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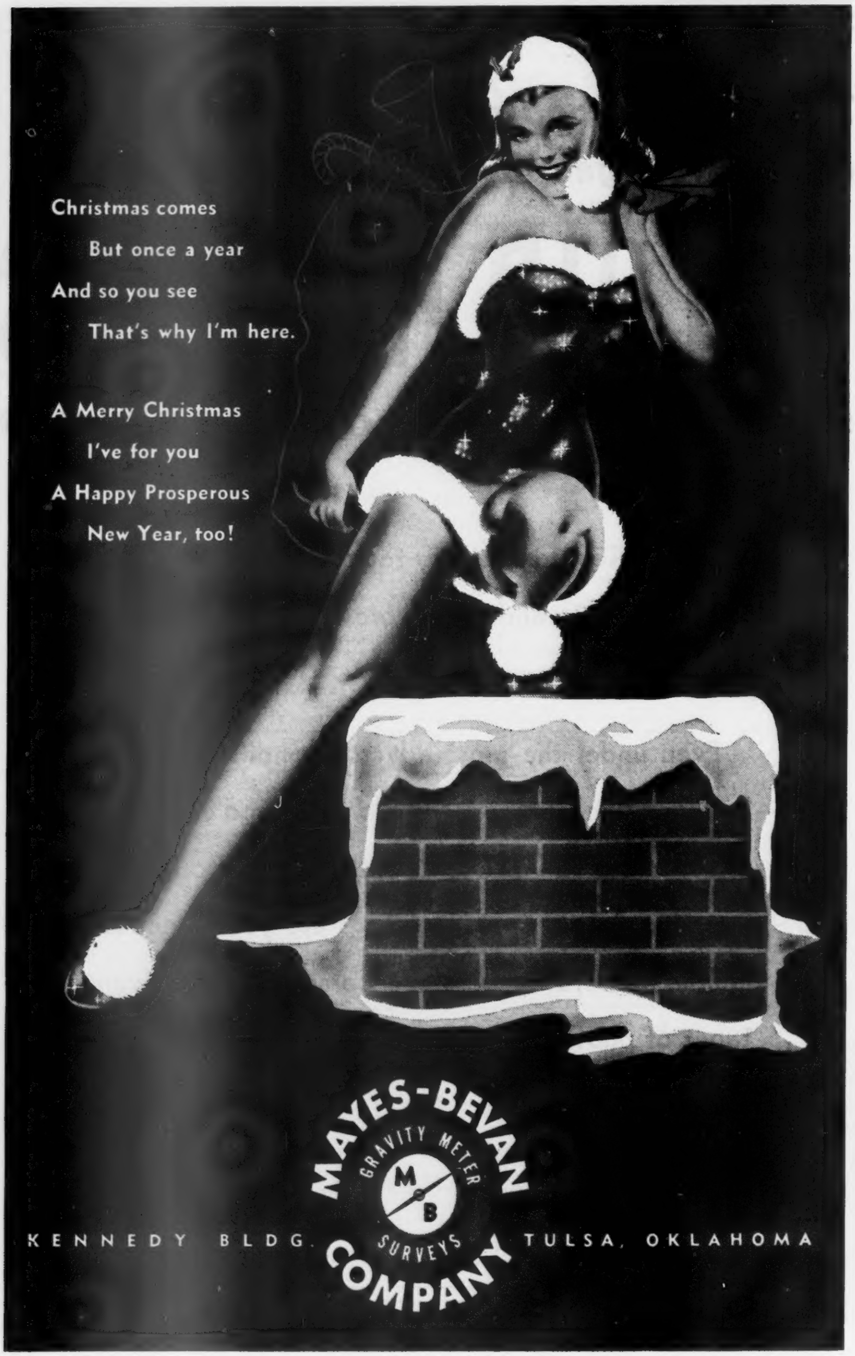
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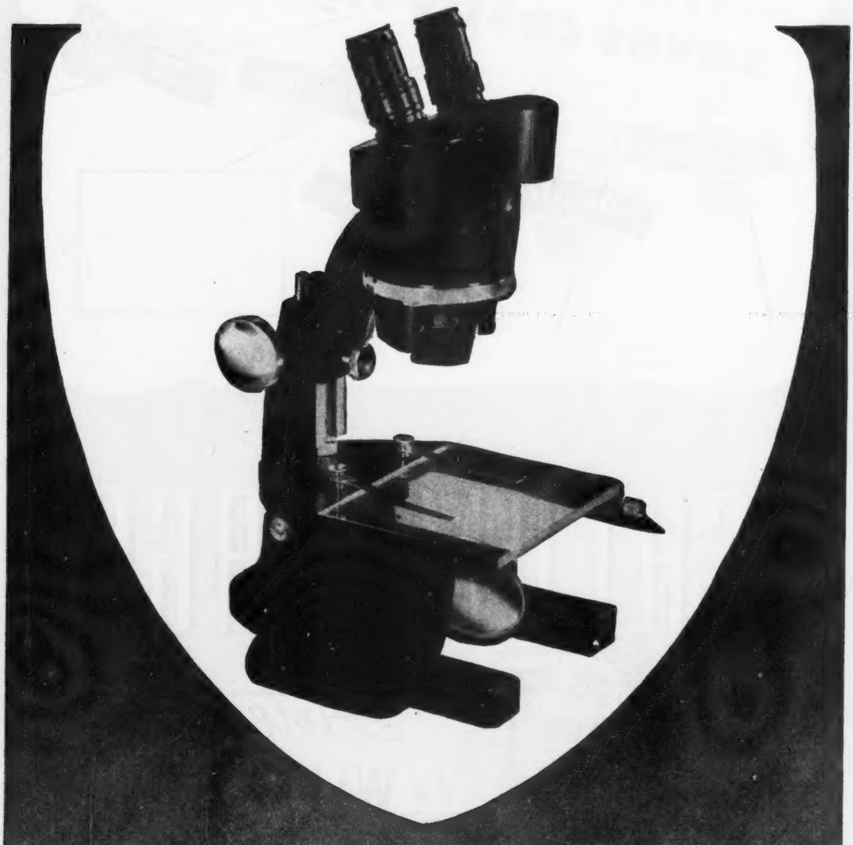

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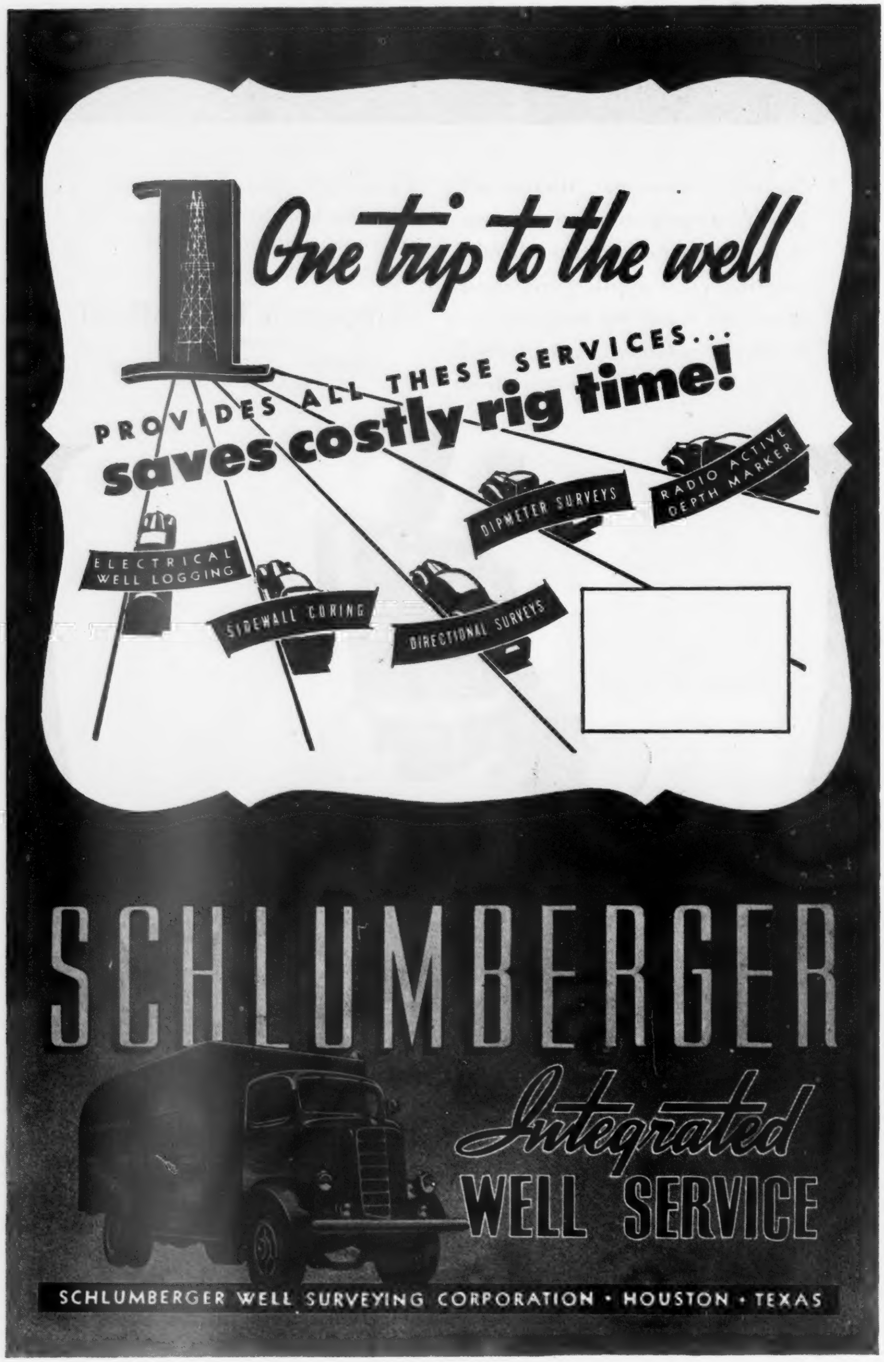

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DISTRIBUTION OF OCEANS AND CONTINENTS—A SUGGESTION[1]

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Melbourne, Victoria, Australia

ABSTRACT

The paper is an attempt to reconcile two apparently contradictory theories regarding the distribution of oceans and continents on the earth's surface, namely, the Tetrahedral theory and Wegener's hypothesis. Each of these theories accounts eminently satisfactorily for a large series of important objective facts; but, by itself, fails to explain another series of equally important facts inherent in the other.

The Tetrahedral theory has a sound mathematical and physical basis. The antipodal distribution of lands and oceans on the earth at present is in such close agreement with the positions demanded by theory that the "fit" can not be disregarded and looked upon as entirely fortuitous. Yet there are outstanding anomalies such as the overlap of Patagonia and China in an antipodal map, and the position of the northern continents with an average latitude of 45° N. Such discrepancies must be explained if possible.

Wegener's hypothesis accounts for so many undisputed facts in connection with geology, paleontology, and climate, otherwise absolutely incredible, that its main thesis of continental drift must be accepted, at least as far as the southern continents and India are concerned. The glacial features of Gondwana land, the distribution of the *Glossopteris-Gangamopteris* flora, and of the associated marine and land faunas of all the southern continents and of Peninsular India fit into the framework of a southern continent, with a center of ice distribution near Madagascar. No other suggestion can account for the objective facts involved. For South America, South Africa, India, Australia, and Antarctica to present the evidences of former close association which they unquestionably do, nothing but continental drift on a major scale can be visualized.

Reasons are given for suggesting that the outstanding anomalies may be eliminated, and the apparent paradoxes brought into complete harmony by assuming that, while the tetrahedroid tendency of a contracting and solidifying globe has played a very important part in earth history, its initial stages of development were interfered with and distorted by the early asymmetrical development of the Pacific Ocean basin, which is still a geographical element of abnormal character and dimensions. Whatever may be the ultimate cause of this gigantism of the Pacific Ocean, the fact is an objective one.

It is suggested that the theory put forward by G. H. Darwin, that the Pacific Ocean represents the scar left on the earth mass by tidal separation of the moon, be reëxamined from a new angle. The bulk of the paper is devoted to an analysis of the results of such a phenomenon, which may, by analogy with physiological nomenclature, be termed a traumatic lesion of the earth body.

[1] Manuscript received, April 3, 1946.

[2] "Callabonna," Park Avenue, Gordon, New South Wales. Late geological adviser to the Commonwealth of Australia. The writer desires gratefully to acknowledge the valuable assistance given by Frank Canavan, geologist, Broken Hill Proprietary Company, Limited, Melbourne, who discussed the problem and had the manuscript and figures prepared for publication by members of his staff.

Reasons are given for supposing that such an injury, taking place some time after the earth had developed a permanent solid crust, could have caused "congenital deformity" of the embryonic tetrahedron, the development of which can be visualized as commencing some time after the initial formation of a solid crust. It is thought that the presence of the Pacific scar was responsible for the displacement of the Antarctic quoin of the tetrahedron toward South Africa, which is antipodal to the Pacific depression. The dihedral edges of the tetrahedron connected with this quoin were similarly twisted, leading to the development of the Gondwana continent.

Incidentally, it is suggested that there is no need to assume, as is done in Wegener's hypothesis, that the center of ice distribution in Permo-Carboniferous time was the South Pole of the earth of that period. This assumption involves a number of serious paradoxes, and is not acceptable to astronomers and geophysicists.

It is thought that the traumatic lesion of the earth was more severe in the South Pacific than was the case in the North Pacific, and that the development of the northern continental masses in such high northern latitudes may be a consequence of this.

As cooling of the earth proceeded, and ever deeper zones of the earth's interior ceased to alter their surface areas, the tetrahedroid tendency asserted itself in them. Such deeper zones were not controlled by the Pacific scar. As the tetrahedroid stresses accumulated they attained critical dimensions and carried the roots of the continental masses imbedded in the contracting zones nearer to the positions of ideal tetrahedroid symmetry. This gives a motive power for Wegenerian drift which is lacking in the original presentation.

Since accumulation and relief of stress are both gradual, a reason is provided for the periodicity of eras of orogeny. At the same time adequate amounts of kinetic energy, always a problem in dealing with the phenomena of diastrophism, are made available. Such effects are in no way exclusive of the results of radioactivity, sedimentation of geosynclines, internal flow of earth temperatures, and so on, but are complementary to them.

Reasons are adduced for believing that it was not until the initiation of Hercynian diastrophism that "dehiscence" of the Gondwana land knot occurred, initiating the rapid and extensive continental drift which has been shared by all the southern continents and Peninsular India.

The immediate effects of this drift are examined. It is shown that India has not yet reached its normal tetrahedral position between the Sino-Siberian shield and the Western Australian one, having been delayed by having had to plow through the enormously thick sediments of the great geosyncline of southwestern Asia, which geosyncline must be interpreted as the functional northerly extension of the Indian Ocean. In its later movements India has caused the crumpling of the greatest mass of fold mountains in the world.

South America, also, has not yet reached its allotted place in the tetrahedral symmetry, south of the Canadian shield. Had it done so, it would have become exactly antipodal to the Turkestan-Caspian region, which, as just mentioned, is functionally the northern end of the Indian Ocean.

A further suggestion is that when the Pacific was produced the ragged edges of the scar were left, and have persisted ever since as a circum-Pacific ring of earth structure. The possible effects of such a highly hypothetical structure are analyzed, and the suggestion is advanced that it may assist in explaining certain tectonic features such as the distribution and limitations of Laramide folding, and the remarkable loops and tectonic complexities encountered in the Caribbean, Moluccan, and Falkland Island regions.

INTRODUCTION

Of attempts to solve the problems connected with the distribution of land and sea on the earth's surface, and of their relations to tectonic zones, there is, as in "the making of books," no end. Many of the most accomplished thinkers have approached the subject and have propounded theories more or less plausible; but still there remain anomalies, contradictions, and paradoxes. The writer has no hope of solving finally this riddle of the Sphinx, but it is possible that the suggestions here advanced may attract others to approach this intriguing and profoundly important subject from a different angle.

Two outstanding hypotheses concerning the distribution of continental masses on the earth's surface have, individually, so many points in their favor that it seems incredible that either of them should be fundamentally fallacious. Yet, at first glance, they appear as paradoxical as the co-existence of light and darkness.

Each hypothesis seems to account perfectly satisfactorily for a wide range of objective phenomena of whose existence and magnitude there can be no doubt. The hypotheses in question are the Tetrahedral Theory of Earth Form, elaborated from the data of earlier workers by J. W. Gregory 50 years ago, and the intriguing Theory of Continental Drift advanced by Wegener. The one hypothesis appears to indicate the essential permanence of oceanic and continental sectors; the essence of the other is the almost incredible mobility of continental features.

Is there no possible suggestion which can bridge the gulf separating them?

OBJECTIVE FACTS

The following objective facts[3] in relation to earth form and structure include some of the most important which must be accounted for by any acceptable theory. The list is by no means exhaustive.

1. Uniqueness of size and form of the Pacific Ocean basin
2. Extreme complexity of the tectonic features of the East Indies and Caribbean areas; and of the Cape Horn region (?)
3. Circum-Pacific development of Laramide folding
4. The great continental mass of Europe, Asia, and Africa
5. Comparatively symmetrical arrangement of earth units in relation to the terrestrial axis of rotation
6. Situation and permanence of Archean shields
7. Antipodal arrangement of continents and oceans
8. Tetrahedral theory
9. Permanence of ocean basins: rarity or absence of true abyssal deposits on continental areas
10. Wegener's hypothesis
11. Structural, paleontological and climatic unit of Gondwana land
12. Periodicity of principal eras of orogeny
13. Migration of loci of tectonic action
14. Relation of granitic injections to mountain folding

It is proposed to divide this paper into two parts: the first dealing mainly with the outstanding features of the objective facts already referred to, with incidental references only to their theoretical implications; the second part developing the more speculative ideas which constitute the thesis of this paper. Suggestions are advanced for testing the balance between the objective facts and the minor speculations arising therefrom. Several frankly speculative suggestions are put forward. These do not appear to be capable of either proof or disproof; and their acceptance or rejection is not vital to the main thesis.

PART I

I. UNIQUENESS OF SIZE AND FORM OF PACIFIC OCEAN BASIN

The most perfunctory inspection of a map of the earth, on any kind of projection, reveals the fact that the Pacific Ocean basin is much the most extensive individual unit of terrestrial structure. Its colossal area, the comparatively simple

[3] Items 8 and 10 in the list are not objective facts, strictly speaking. Since, however, only those aspects of these questions which will be universally accepted by the majority of geologists are dealt with in this section, they have purposely been included here. The debatable aspects are relegated to the second part of the paper in which controversial subjects are dealt with.

contour of its boundaries and the absence from it of any considerable land masses all require investigation and explanation.

Its dominating importance as a terrestrial unit becomes ever more and more apparent as the nature and structure of its islands are examined, the individual characteristics of its shore lines are studied, and its relation to continental drift is made apparent.

When all these facts are considered together, and in direct contrast with the features of other ocean basins, it is difficult to escape the conclusion that so enormous and unique an element of earth structure demands some stupendous and unique mode of origin.

So great an astronomer and mathematician as G. H. Darwin did not hesitate seriously to advance the suggestion of the birth of the moon as the result of budding-off of an excrescence from the earth's mass as a result of rotational effects. He went so far as to compare the volume of the moon with the volume of the Pacific Ocean depression, and to venture the suggestion that that great and anomalous earth unit represented the moon scar. Certainly this suggestion has been violently opposed by many leading men of science, and few, if any, have the temerity to accept it wholly. Still, it is a suggestion put forward seriously by a great thinker, and, as such, is entitled to respectful consideration. No other satellite in the Solar system bears to its planet a mass relationship at all comparable with that which exists in the case of the Earth–Moon couple. This, in itself, suggests a mode of origin out of the usual.

Another suggestion is that the Pacific depression was scooped out by the impact of a colliding heavenly body, or as the result of the excessive tidal effects of a very near approach by one.

Whatever be the origin of the depression, the objective fact is that the Pacific Ocean is an anomalous earth unit. If it is of very ancient origin it must have imposed an initial asymmetry on all subsequent development—an influence which, the writer believes, it is still exerting.

2. EXTREME COMPLEXITY OF TECTONIC FEATURES OF EAST INDIES AND CARIBBEAN AREAS: AND OF CAPE HORN REGION (?)

In dealing with Cenozoic tectonics it is usually held that the zone of Alpine folding completely surrounds the Pacific Ocean, involving formations of late Mesozoic and early Tertiary age in its compression.

The main zone of Alpine folding, however, begins in western Europe, includes the whole of the mountain systems of southern Europe and those of northern Africa, those of Asia Minor, the Himalayas and southern Siberia; then, with sharp flexure of strike, the foldings of the Malay Peninsula and of the partially submerged mountain axis of the East Indies, abutting almost perpendicularly on the circum-Pacific ring in the extraordinarily complex tectonic knot of the Moluccas. In regard to this particular sector there has been much controversy, and no finality appears to have been attained.

On the other side of the Pacific, "Alpine" folding runs the whole length of both Americas, and there is a second region of high tectonic complexity in the Caribbean area.

A third region of considerable complexity, marked by extraordinary looping of the fold axes, exists at the extreme southern end of South America, and runs through the Falkland and South Shetland islands into Antarctica. From its situation this region has attracted less general attention than have the other two.

3. CIRCUM-PACIFIC DEVELOPMENT OF LARAMIDE FOLDING

Around the Atlantic and Indian oceans there was no general development of the late Mesozoic diastrophism which is so strongly marked and well differentiated in the Rocky Mountains of North America, where it is referred to by American geologists as the Laramide period of orogeny.

Obruchev[4] and other Russian geologists emphasize the existence of a similar epoch of diastrophism in eastern Asia, so that its development appears to be bilateral with regard to the *northern* Pacific. On the shores of the *southern* Pacific such Laramide folding is by no means so outstanding a feature, if, indeed it can be recognized as a separate entity.

The foregoing facts appear to be objective enough to be widely accepted. The more subjective and speculative analysis of them will be attempted later.

4. GREAT CONTINENTAL MASS OF EUROPE, ASIA, AND AFRICA

A second unit of earth structure, scarcely less disproportionate than is the Pacific basin, is the composite continental mass of Europe, Asia, and Africa. A little reflection, however, will show that this great land mass possesses features in strong contrast with the essential unity and homogeneity of the Pacific Basin. The continental mass exhibits the greatest possible degree of heterogeneity. It is possible to subdivide it into units of the most diverse and contrasted characters, some of which, like the pre-Cambrian shields of Fennoscandia, of eastern Siberia and China, and of most of Africa, contain some of the most ancient rock masses on the earth.

Four great periods of orogeny (at least), Huronian, Caledonian, Hercynian, and Alpine, seam the continents, involving vast extents and thicknesses of marine and continental formations deposited throughout the whole of post-Archean time in extensive marine and epicontinental basins (but not in deep oceans), and now included within the boundaries of the composite continental mass.

It is of vital importance to realize, however, that the great land mass in question has not always been so continuous as it is now. Throughout the greater part of geological time the European mass on the west was separated from the Siberian mass on the east by oceanic basins. The sediment-filled trough of the

[4] A. Obruchev, Review of book by M. M. Tetyaev, "Osnovi geotektoniki" (Fundamentals of Geotectonics), Isvestiya Academii Nauk, Geol. Ser., No. 3 (1943), pp. 107–27.

Hindu Kush, Tian Shan, and Khirgiz areas must be regarded as structurally the northern extension of the Arabian Sea; a matter of the highest moment in much of the subsequent discussion.

If, as is necessary for the problem immediately confronting us, we emphasize the distribution of the most ancient formations and leave out of consideration, in the initial stages, the younger geosynclinal deposits, the unity of the great continental knot disappears. Certain less apparent, but actually more fundamental, connections can then be traced between units, which, at first sight, do not appear to belong to the general picture.

5. COMPARATIVELY SYMMETRICAL ARRANGEMENT OF EARTH UNITS IN RELATION TO TERRESTRIAL AXIS OF ROTATION

The distribution of the continental masses, certain broad features of their forms, and some of their geological structures require satisfactory explanation. While the shapes are very irregular as regards individual outlines there is a general tendency toward triangular form, with a broad base contiguous to the Arctic Ocean, and a tapering-out in the middle latitudes of the Southern Hemiphere.

If we eliminate from consideration, temporarily, that section of the Eurasian continental mass which separates the European shield from that of Siberia, we have the triangular shape aforementioned more or less completely exemplified by three complex and distorted earth units:

(1) The Americas, rather perfectly; in spite of the strong kink east of South America,
(2) Europe and Africa, reasonably perfectly,
(3) Sino-Indian-Australian mass, much broken and distorted.

A second systematic feature in this distribution is that the northern, basal sections of all the triangles lie roughly on the same broad belt of latitude, with a mean central line situated about 45° north of the equator.

Thirdly, within this zone the central points of the three continental nuclei are situated in longitudes about 100° W., 10° E., and 120° E., respectively. Again the asymmetry of the Pacific Ocean becomes apparent. If it were not for this fact we should have a quite reasonable approximation to a symmetrical distribution of 120° in terms of the longitudinal separation of the major nodes.

Fourthly, in the southern hemisphere the tapering of the continents is rapid and conspicuous; so that this hemisphere, apart from Antarctica, is dominantly ocean-covered.

The Eurafrican triangle tapers off *above sea-level* at the Cape of Good Hope, about 33° S., though the submerged Aguhlas Bank carries the line, with continuance of the tapering, to about 45° S.

The Sino-Australian triangle reaches to about 45° S., again allowing for the extension of comparatively shallow sea bed south of Tasmania.

The American triangle *appears* to spoil the general symmetry by running down to a very sharp and strongly recurved point at Cape Horn in latitude 55° S.

As shown later, there are reasons for considering that the southern part of Chile and Argentina may be regarded as a geological unit distinct from the more northerly parts of Argentina. If South America can be tapered off somewhere about the Gulf of St. George at 45° S., its interference with the general symmetry disappears.

Subject to distortions and irregularities, which require explanation, there is, therefore, a rough sort of symmetry in continental distribution, ***conforming with the existing axis of rotation*** of the ***earth***. This involves as sub-Arctic zone of continental land masses, a sub-Antarctic girdle of ocean, meridional axes for the three continental groups, and a conspicuous southerly tapering of each continental mass.

6. SITUATION AND PERMANENCE OF ARCHEAN SHIELDS

When note is taken of the distribution of the major areas of very ancient geological formations their associations with the continental nuclei becomes very apparent. A large part of Canada, excluding the western parts, consists of pre-Cambrian formations. Their extension southward as a basement under the eastern part of the United States can be inferred.

They reappear in Brazil, and are traceable southward far below the Tropic of Capricorn.

Practically the whole of Scandinavia, Finland, the Ukraine, and surrounding areas are composed of, or immediately underlain by, ancient shield rocks. Considerable areas are present also in the British Isles and in central France. The greater part of Africa is composed of ancient shield rocks.[5]

Eastern Siberia and the adjacent parts of China are built up of pre-Cambrian schists, and constitute one of the most important nuclei of such formations.

The western two-thirds of Australia are occupied by similar formations, thinly covered in places by remarkably undisturbed later sediments.

The important mass of ancient rocks underlying peninsular India and Ceylon, while petrographically forming a unit closely related to the Siberian-Chinese massif on the one hand, and to the Western Australian massif on the other, is conspicuously out of line with those masses, lying far west of the meridian passing through them.

Lastly, much of Antarctica is known to consist of crystalline schists and gneisses strikingly similar to those of the western parts of Australia.

Broadly, then, and subject to distortions and lacunae which must receive explanation, the meridional axes of the continental triangles are marked by ribs of ancient crystalline schists, and Antarctica is composed of similar rocks. India is the only considerable area of similar formations which does not fall within the limits mentioned.

In every instance, also, these areas show every sign of having persisted as

[5] F. Blodin, *La géologie des mines de vieilles plateformes*. Société d'Editions Géographiques, Maritimes et Coloniales (Paris, 1936). 301 pp.

continental lands from earliest time, and of having never been involved in major geosynclinal subsidences.

7. ANTIPODAL ARRANGEMENT OF CONTINENTS AND OCEANS

Inspection of a terrestrial globe reveals the striking fact that the continents and ocean basins are *almost* completely antipodal to one another. Of course, since the oceanic area is so much greater than that of the continental lands, there is still a large excess of water.

The same phenomenon can be made more immediately apparent by drawing an antipodal map, such as is shown in Figure 1. To construct such a map, trace to

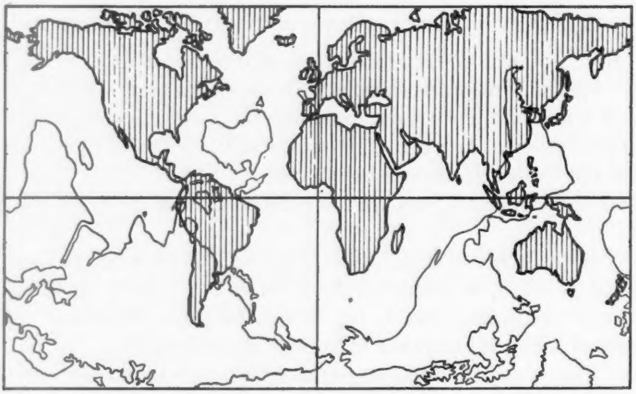


FIG. 1.—Antipodal map of the earth.

outlines of the continents on a sheet of tracing paper, with the 180° meridian centrally situated. Turn the tracing back to front and upside down, and apply to the base map with the 180° meridian of the tracing coincident with the zero meridian of the base map. Trace the outlines again. The two tracings will now be antipodal in position.

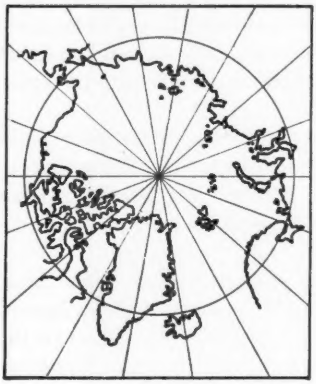
Because of the excessive distortion in high latitudes of Mercator's projection, it is advisable to restrict the figure to 70° each side of the Equator, treating the polar regions separately in polar projection (Fig. 2.).

The striking opposition of continents and oceans is clearly brought out by these diagrams. It will be seen that the Eurafrican mass in the reversed map falls in the Pacific Ocean of the direct one. Asia and Australia lie respectively in the South and North Atlantic, and the Americas *almost* entirely lie in the Indian Ocean. There is a decided overlap of Patagonia into China; and this discrepancy has to be explained. This is done in the second part of the paper.

Another minor discrepancy is that antipodal Antarctica is a very tight fit in

the Arctic Ocean of the base map. Tentative suggestions regarding Antarctic structure are dealt with later.

Taken in conjunction with all the other objective facts relating to the distribution of continents and oceans, it is impossible to consider that so close an agreement with ideal antipodal symmetry is entirely fortuitous.



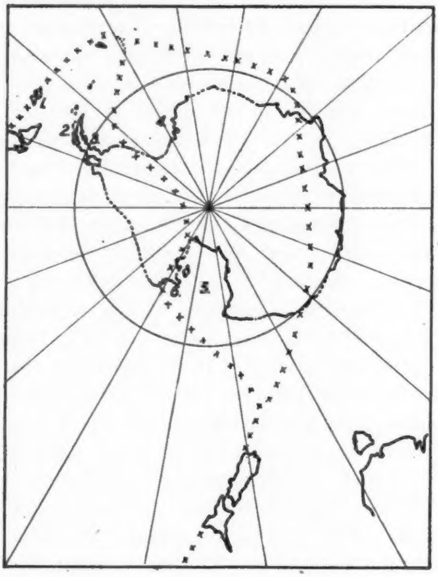


FIG. 2.—Arctic and Antarctic regions. Crosses indicate alternative suggestions (very tentative) for limits of primordial Pacific Ocean.

1. Falkland Islands
2. South Shetland Islands
3. Graham Land
4. Weddell Sea
5. Ross Sea
6. King Edward VII Land

8. TETRAHEDRAL THEORY

The foregoing objective facts fit more or less neatly into the framework of Tetrahedral hypothesis of earth structure which was somewhat extensively canvassed 50 years ago. This elegant and arresting theory does not appear to the writer to have received from geologists anything like the attention it merits. Many of the younger generation may not even have heard of it; so that it appears desirable to outline its main features in summary fashion.

Of all solid figures, that which possesses the *minimum surface* for a *given volume* is the sphere. Hence, any fluid body acted on *only* by the force of surface tension, tends to assume spherical shape. The proviso emphasized in the last

sentence is rarely, if ever, completely fulfilled in nature. Even the raindrop is affected by gravitation and by air resistance which tend to distort it. Most of the non-gaseous heavenly bodies closely approximate the spherical form, though distorted by reason of rotation into slightly oblate spheroids.

If such a heavenly body, originally liquid or plastic, develops a rigid crust and then continues to contract, a new set of conditions is set up. Of all solid figures, that which possesses the *minimum volume* for a *given surface* is the regular tetrahedron, bounded by four equal equilateral triangles. That a *tendency* exists for a contracting sphere of fixed surface to shrink tetrahedrally can be shown by coating a sphere of colloidal material with a rigid shell sufficiently porous to permit *slow* evaporation of the solvent. The writer attempted to demonstrate the effect by filling a metal sphere with steam and cooling it.

Only occasionally are the results of such an experiment really striking; since it is difficult to secure absolute homogeneity of composition, and absolute regularity in decrease of volume, particularly within the time available for a laboratory experiment. Both methods, however, have suggested a *tendency* in the direction postulated.

A moment's inspection of a tetrahedron shows that it possesses four *faces*, each of which is an equilateral triangle. It has four sharp points or *quoins* formed by the concurrence of three adjacent faces. A line from any quoin through the center of the figure passes through the central point of the opposite face: in other words, faces and quoins are antipodally situated. The figure possesses six edges or *dihedral angles* each of which is the common section of two adjacent plane faces.

If such a solid figure is adjusted concentrically to a sphere whose radius is a little less than the distance from the common center of the figure to one of the quoins (Fig. 3.), the four quoins will project above the spherical surface as four triangular pyramids, each on an equilateral small spherical triangle as base. If we imagine the sphere to be composed of water, and the tetrahedron of land, we obtain four "continental" masses, each antipodal to an oceanic sector.

If we assume for a moment that such a state of affairs could have developed in an incipient form in the cooling of an originally viscous, spheroidal, rotating earth, and in the accumulation round the common center of gravity of a spheroidal ocean, it does not seem likely that the generation of the tetrahedron could have been anything but symmetrical with the axis of rotation. This is probably mathematically demonstrable; but the writer is not capable of developing the formula.

It is to be noted that the regular tetrahedron possesses four *triad* axes of symmetry, passing through the quoins and the centers of the opposite faces; and three *dyad* axes passing through mid-points of dihedral edges. From the analogy of a spinning top it would appear that the most stable axis of rotation is the line forming the axis of symmetry of the highest order. In the case of the spinning tetrahedron any one of the four axes could be selected; but once the spin was initiated, it could scarcely be changed from one axis to another. Though all four axes in a perfectly homogeneous tetrahedron are completely interchangeable with

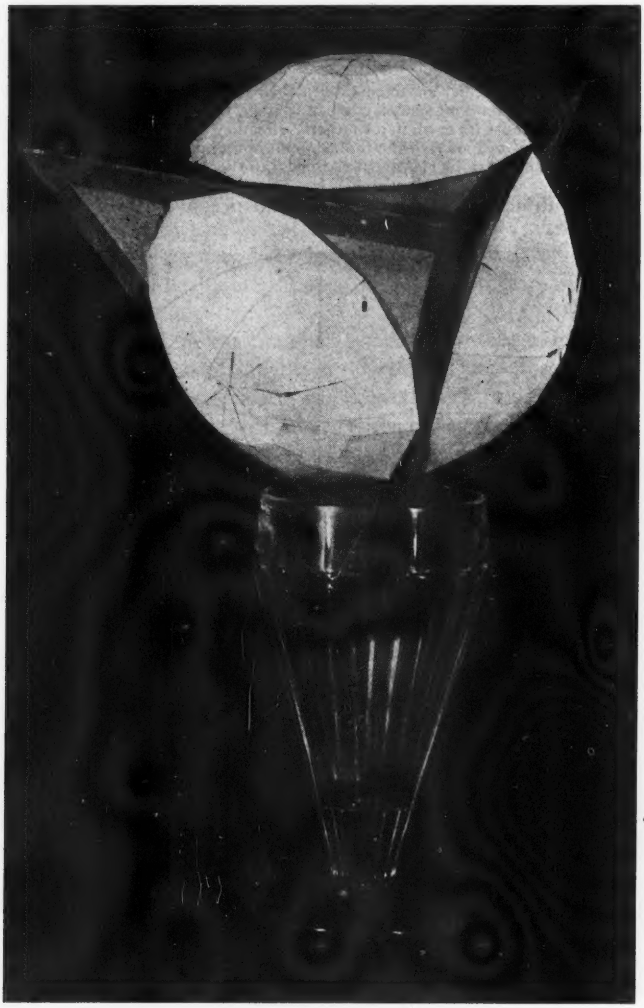


FIG. 3.—Model of tetrahedron and sphere in equipoise.

one another, even a slight degree of heterogeneity would favor selection of one or other of them.

If we assume, further, that this is the case, and also that the solid matter is absolutely homogeneous and absolutely isotropic in regard to every physical and

chemical property, our ideal earth should have the relations indicated diagrammatically in Figure 4. This involves:

(1) A deep Arctic Ocean,
(2) Three northern triangular continents, with their centers spaced at longitudes 120° apart, round the circumference of a small circle of latitude 19½° north of the Equator,
(3) Each continent must taper off in a southerly direction,
(4) Each continent is antipodal to the central point of an opposite ocean,
(5) There will be an Antarctic Continent antipodal to the Arctic Ocean.

The relative dimensions of continents and oceans will depend on the ratio

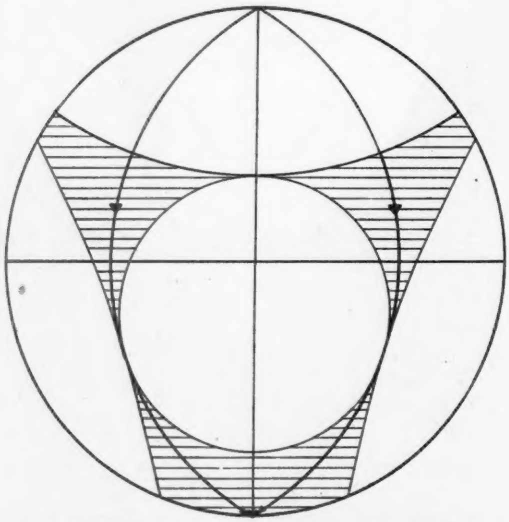


FIG. 4.—Tetrahedron and sphere in equipoise. Stereographic projection. Small black triangles indicate quoins of tetrahedron inscribed in sphere; therefore, central points of "continental" areas. Apparent inequalities in sizes and apparent distortions in shape of different oceanic and continental areas are due to distortion inherent in stereographic projection.

between the radius of the oceanic sphere (actually a spheroid, nearly spherical), and the distance from a continental quoin to the center. With a suitable choice of this ratio, the southern apices of the continents will reach well below the Equator. Under such conditions the three northern continents will stretch out toward one another, and will be united by sub-oceanic ridges covered by comparatively shallow water, along the lines of the dihedral edges.

From what has been said in section 6, it appears that the existing distribution of the most ancient areas of rock formations is a "colourable imitation" of the state of affairs postulated, though so distorted and so irregular as to be a mere libellous caricature of the ideal arrangement.

If there is anything in the suggestion of a *tendency* toward tetrahedroid de-

velopment, reasons for the discrepancies and an apology for the distortions must be forthcoming.

The first assumption made on page 1990 is sufficiently close to the objective facts as not to need any special pleading.

The second and third assumptions, however, are clearly not applicable to a body like the earth at the present day, and are very unlikely ever to have been fulfilled. While every modern cosmogenic and geophysical theory holds that the earth mass consists of concentric zones of different composition and specific gravity, it does not insist on complete homogeneity and isotropism in each individual shell. That there may have been streaks and patches in the original sial envelope can scarcely be doubted. Hence, absolute symmetry of development can hardly be expected.

Above all, we have the outstanding asymmetry of the unique Pacific Ocean to consider. If this can be explained as an extremely early phase of terrestrial embryology, the residual distortion of continental distribution does not appear excessive. This aspect is dealt with in the second part of the paper.

9. PERMANENCE OF OCEAN BASINS: RARITY OR ABSENCE OF OF TRUE ABYSSAL DEPOSITS ON CONTINENTAL AREAS

If it be granted that the Tetrahedral theory is admissible as a basis for serious discussion, some of its corollaries must receive consideration.

Since, on this hypothesis, oceanic sectors are areas of constant shrinkage and depression, the permanence of ocean basins appears to be an inescapable deduction. The continental quoins are not, so far as radial distance from the center of gravity is concerned, areas of uplift; but they are, rather, points of minimum shrinkage. There is no reason why secondary effects, such as subcrustal variations of temperature, pressure caused by sedimentary loading, crustal folding, movements of magma, and many other factors should not occasionally superimpose actual upward movement. Even apart, however, from any such actual uplift, continued deepening of the facial segments of the tetrahedron, resulting in increased concentration of oceanic waters in the depressions, must leave the primeval quoins progressively higher above mean sea-level as evolution proceeds. Such original projections, then, continue throughout geological time as areas of dominant subaerial erosion. Such erosion, keeping pace with the "uplift" prevents the quoins from appearing, at any stage, as huge excrescences. They are worn down continually to their very roots and reveal the deepest layers of the earth's interior accessible to direct observation. They do not participate to any considerable degree in later oscillations and foldings which affect regions peripheral to them. This is quite in consonance with the universally known facts of the geology of major pre-Cambrian shields wherever they occur.

It is realized that there is considerable diversity of opinion about the presence of representatives of true abyssal red clay formations on continental surfaces. The writer has dealt with this question previously, and has expressed strong doubt

in relation to most of the occurrences which have been claimed as representatives of this class. Until it is clearly proved that true abyssal formations are met with on continental surfaces the matter must be regarded as ***sub judice.***

10. WEGENER'S HYPOTHESIS

The Wegener Hypothesis of Continental Drift has been so extensively and exhaustively discussed of recent years that it is unnecessary to remind geologists of its main features. In spite of many important objections in matters of detail, there seems to be no reasonable escape from the view that only a Wegenerian movement is capable of explaining a host of paradoxes affecting the ***southern*** continental areas.

To the writer it has always seemed that the case for the northern continents is extremely weak, and that most, if not all the similarities of geological structure on the eastern and western sides, respectively, of the northern Atlantic can be explained reasonably well without resorting to extensive continental drift. It is proposed to show later how this may be done by means of the Tetrahedral theory. Any claim of considerable drift of North America and Asia rests on evidence much less objective than that which indicates so clearly the Wegenerian drift of the southern fragments of the pre-Cambrian shield.

It is generally, and apparently rightly assumed that it is some sort of drift toward the Pacific depression which has been the motive force impelling the wanderings of India and Australia in an easterly direction, of South America westward, and of Antarctica southward. In the original Wegenerian concept Africa was regarded as a permanently stable block. There are reasons, however, for the view that this stability is relative rather than absolute.

One of the strongest arguments in reference to the drift of the southern fragments, namely, Gondwana land and its glaciation, is dealt with somewhat more fully in the following section. Here it is desired to emphasize a feature, already well developed by the Wegenerians, namely, the influence of continental drift as it affects Alpine orogeny; but with particular reference to the Australian sector which is, perhaps, less familiar to many geologists than are the manifestations of this action in northern latitudes.

A northerly movement of the African mass, crushing the Mediterranean deposits against the foreland of the Caledonian and Hercynian folds of Central Europe can help greatly to account for the structures of the circum-Mediterranean area.

A much more active and extensive northeasterly movement of the Indian fragment can be visualized even more clearly. The mighty east-west foldings of the Hindu Kush and Himalayas, and the sudden and extraordinary right-angled bend into the line of the Malayan axis can be illustrated almost perfectly by pushing a board through the thick cream on a cheese vat (a homely but instructive experiment).

Quite as clearly the wrinkles north and east of Australia are explained in a

similar way. There are many clues which suggest that Australia's career of drift (no political implications involved) has been even more rapid and extensive. Unlike India, however, it has had no main continental foreland opposing it, although another, highly tentative suggestion is advanced in a later section of this paper.

As there was only one *effective* jaw to the vice the wrinkling caused by the drifting Australian mass failed to produce a counterpart to the Himalayas, and lifted considerably only the mountains of New Guinea.

It may not be widely known outside of Australia that drilling for oil near the mouth of the Fly River of New Guinea has demonstrated the fact that the continental massif of the Australian mainland continues under Torres Strait and well into the hinterland of New Guinea. The Tertiary sediments resting on these continental rocks are undisturbed in this area. Farther to the east late Tertiary sediments exhibit true Alpine fold structures. It is suggested that the marked kink in the mountain axis of New Guinea near the Dutch-British border marks the point where the "keel" of New Guinea has been broken by the "bow-on collision" of the advancing Australian "ram."

The sweep of the plastic sector round the Australian mass like the grain in a piece of pine timber curves round a knot in the wood may be interpreted as an indication that Australia, like India, is an intruding foreign element of earth structure. This is a matter of enormous importance to Australia in connection with the search for oil.

II. STRUCTURAL, PALEONTOLOGICAL AND CLIMATIC UNITY OF GONDWANA LAND

Most of the geologists of Europe, Asia, and North America, though they are of course, aware of the main facts, scarcely realize the extent to which we, in the Southern Hemisphere, have our thoughts influenced or dominated by the extraordinary uniformity of geological formations, of fauna and flora, and particularly of glacial phenomena of about Carboniferous and Permian age constituting the absorbing problem of Gondwana land.

The closest of analogies exists between the geological features of the different elements building up the now isolated fragments of pre-Cambrian shield areas in South Africa, India, and Australia. This similarity is always commented on by geologists from India or South Africa who are visiting Western Australia. With the details of the Brazilian mass we are less familiar; but descriptions of the itacolumites and iron ores of that country might well have been written to describe similar formations in Western Australia.

Without going into details, the reader may be reminded of the close identity of the *Gangamopteris-Glossopteris* flora and of the corresponding marine and terrestrial faunas of Argentina, Uruguay, South Africa, India and Australia. Though little detailed work has yet been done, the general close agreement of the Beacon sandstone series of Antarctica with rocks of Permo-Carboniferous age in Australia suggests that the unknown continent forms part of the picture.

One of the outstanding puzzles has always been the distribution and direction of movement of the ice sheets which produced the glaciated pavements and very thick tillites in all the areas mentioned (Antarctica ?). Most remarkable of all is that in peninsular India, in *present* latitude 17° N., ice sheets reached sea-level travelling *from south to north.* Every detail of Indian glaciation finds its counterpart in that of Western Australia, where, again, heavy tillites occur within 17° of the present Equator.

As has been described in great detail by the protagonists of continental drift,

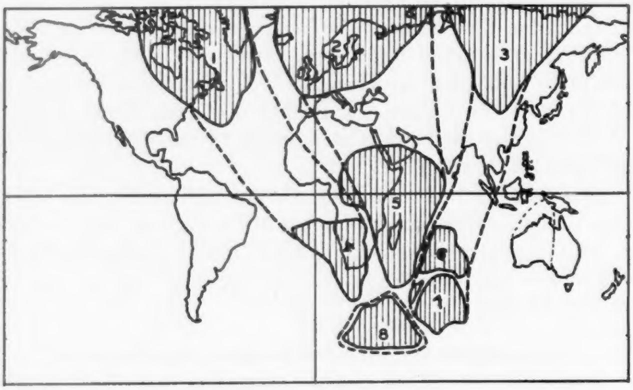


FIG. 5.—Distorted tetrahedral earth. Pre-Hercynian. Slopes of numbers suggest amount of rotation experienced by different continental units in reaching their present terrestrial positions.

1. Canadian shield
2. Scandinavian shield
3. Asiatic shield
4. Brazilian shield
5. African shield
6. Indian shield
7. Western Australian shield
8. Antarctic shield

these anomalies dovetail with amazing exactness and completeness if, and only if it is assumed that, during Gondwana time, South America abutted against Africa on the west, India and Australia did so on the east, and Antarctica on the south (Fig. 5.).

If it is further assumed that the earth's axis of rotation was then different from what it is now, and that the South Pole was situated somewhere in the region of Madagascar, the riddle of the glacial striae *appears* to have been solved.

Opponents of the Wegenerian hypothesis object, and with good reason, that if the South Pole were situated near Madagascar, the North Pole should have been not far from the coast of Southern California; and that, therefore, we should have reason to expect at least some evidences of polar conditions of climate in Permo-Carboniferous time in the southwestern part of the United States.

It has been claimed by Wegenerian extremists that there is evidence of glaciation in some of the conglomerate beds of western Texas; but this claim seems to

have been reasonably refuted by opponents of the theory. Though the writer has not personally examined the type exposures of the conglomerate in question, he had ample opportunities during 1930 of visiting considerable areas of Carboniferous and Permian exposures in Texas and New Mexico under the guidance of leading American geologists. Though the possibility of the existence of glacial phenomena was discussed with them, and though he was more than anxious to recognize its slightest traces, nowhere was anything seen even remotely resembling the glacial phenomena of Australia, with most of whose exposures the writer is reasonably familiar. Nor are the formations in United States comparable with the tillites of Serra Tartagal on the borders between Argentina and Bolivia among which he spent some time.

On the other hand, all the Texan phenomena of Permian time suggest rather the arid conditions of the desert and not of the steppe type.

It is also pointed out, very pertinently, that the fixation of a South Pole in the Indian Ocean would throw Argentina into rather low latitudes, even if South America were close to Africa on the west. This introduces paradoxes of latitude almost as serious as those which it is the object to eliminate.

Astronomers will not tolerate any suggestion of so drastic a change in the earth's axis of rotation as that mentioned; and apparently geophysicists are in agreement with them.

Lastly, so many of the objective facts outlined in the preceding paragraphs appear to confirm an age-long symmetry of distribution of earth features more or less symmetrically arranged with reference to the existing axis of rotation that it appears imperative to eliminate the necessity for invoking a cosmic cause of such magnitude, affecting the earth so late in its planetary history as Permian time.

Very diffidently the suggestion is advanced that the obvious and admitted center of glacial radiation was not the South Pole of the period; but was the center of a very large and very lofty continental land mass. There appear to be good reasons for thinking that this point may have been considerably farther south than the situation usually assigned to it, and that such a situation would eliminate the climatic difficulties in explaining the glaciation of northern Argentina. Such an assumption involves the abandonment of the idea of the fixity of the African mass, and demands at least some movement of the latter in a northerly direction.

Under the conditions postulated, a major ice cap could easily have developed on the higher lands of the Gondwana continent. Such an assumption appears to be more in keeping with the faunal and floral distribution of the time. Although it is known that a rich and varied marine fauna exists at the present time right up to the very foot of the great Antarctic ice barrier, it is not easy to postulate a completely Antarctic climate for the luxuriant *Glossopteris* flora which produced coal so prolifically during the period. That this flora may have been sub-Antarctic in character, and yet abundant enough to give rise to extensive peaty deposits, has its analogies at the present day in the sub-Arctic peats of northern continental areas.

12, 13, AND 14. REMAINING OBJECTIVE PHENOMENA

The remaining objective phenomena listed in the introduction do not require amplification at this point. They are mentioned so that they may take their place in the theoretical and speculative development of the second part of the paper.

Eras of mountain building have occurred at definite epochs in earth history. It appears that such highly active periods of crustal movement were of relatively short duration, and that they were separated by prolonged eras of crustal stability. The intervals between different orogenic epochs were of different durations, but the alternation of active and quiescent periods is a very conspicuous feature. No theory of earth history which fails to present an intelligible reason for such oscillations is worthy of consideration.

Equally important is the fact that successive orogenies indicate that the zones of weakness have undergone considerable modifications during periods of quiescence. After each manifestation of diastrophism has run its course, and has crumpled and metamorphosed the peripheral regions of the stable earth sectors, the folded areas in their turn tend to become solidified to such an extent that, during the next succeeding orogeny, they behave as stable areas. Blodin[6] has emphasized this phenomenon. He points out that the primeval shields have progressively expanded in area, as the result of successive accretions of younger formations which have been profoundly altered in the course of mountain-building processes. As each period of activity has developed, its locus of action has had to migrate farther and farther from the original continental nuclei.

Many writers have pointed out of late years the genetic association of granitic intrusions with zones of diastrophism (an excellent recent summary is given by Kropotkin).[7] The general absence of post-Cambrian granites from shield areas is widely known and has been emphasized by Blodin. In the western two-thirds of Australia, which is a typical example of such a shield, all the numerous granites are pre-Cambrian.

PART II

DISCUSSIONS AND SPECULATIONS

This part of the paper is frankly speculative, and is presented in order to arouse discussion of the highly theoretical and very tentative suggestions advanced. Even if the verdict is an emphatic negative the result can be productive of good so far as geological thought is concerned, since the bright light of searching criticism must illuminate any dark corners filled with uncertainty. The writer desires to emphasize that, while he admits the controversial nature of much of what follows the results are not put forward trivially, but in the good faith of an old man who must very soon quit the stage, and who honestly believes that the suggestions are worthy of serious consideration, and that such consideration may

[6] F. Blodin, *op. cit.*

[7] P. N. Kropotkin, "O proeskhozdenii granitov" (On the Origin of Granites), *Sovyet Geol.*, No. 9 (1940), pp. 32–43.

lead to at least some new lines of thought in dealing with fundamental geological problems.

The main facts of the Wegenerian Hypothesis of Continental Drift appear to be incontestable insofar as they affect the southern continents and peninsular India. If four of the continental masses consisting of ancient shield formations, with solidified accretions of later age rigidly attached to their margins have moved through distances of from 40° to 60° or more of circumferential arc, how can there possibly be any agreement with the Tetrahedral theory, which reasonably explains the *existing* distribution of land and sea, but which fails lamentably to account for the arresting phenomena of Gondwana land?

It is suggested that the rationalization of this apparently crazy pattern is to be sought in the results brought about by the initial asymmetry of the Pacific Ocean. For this reason the sequence of events deduced from this fundamental assumption may be set down consecutively as follows.

After the original development of the earth mass by any of the methods which have been advanced to account for the genesis of the planet, a period was reached when the first permanent crust was produced. The crust was still thin and quasi-plastic, and was presumably of the composition of sial.

Continued evolution thickened and strengthened the crust, leaving it, however, sufficiently elastic to accommodate itself to the movements of the nucleus.

That the surface was a perfect spheroid of revolution is highly improbable. The crust can scarcely have been in an ideal state of perfect homogeneity and isotropism. Even at this early stage land elevations and water depressions may be postulated, so that some sediments could have been formed among the dominant volcanic accumulations favored by the thinness of the crust.

At this stage the Pacific basin was gouged out, the available evidence suggesting that the action was of a violent nature—a traumatic injury to employ a physiological term.

Either the Darwinian hypothesis of moon birth or the impact scar theory for the Pacific basin requires that the earth must have passed from a truly liquid to at least a virtually solid state externally, otherwise no scar could persist, any more than a stone can leave a permanent dint on the surface of a pond. The objective facts of the existence of the Pacific Ocean, and of the petrographic character of its floor and substratum, point to the same conclusion. Hence the development of the depression must have post-dated the first appearance of a solid crust by a period long enough to enable that crust to attain sufficient stability and thickness to prevent the lateral collapse of the edges into the depression. At the same time the date must have been so early that rigidity of the crust had not developed to such a depth as to prevent its yielding to the force of rotation or of impact. Hence it must have been late enough for the earliest supracrustal formations to have developed, but not late enough for virtual constancy of surface area to have been achieved; and therefore before the initiation of a tetrahedral tendency. Does this in any way simplify the lack of ideal symmetry of the northern continental quoins?

A further highly problematical suggestion presents itself.

If the Pacific basin had been produced according to the Darwinian hypothesis, the tidal stresses involved by the close proximity of the satellite must have been stupendous. They would be powerful enough to create not only oceanic tides of titanic dimensions, but immense crustal tides as well; particularly as a relatively thin and as yet non-brittle crust must be postulated. Is it possible that the intense, universal and *sui generis* metamorphism of the Archean formations is assignable, in part at all events, to such a cause?

A still wilder speculation is suggested by a statement by Japp, quoted by John Read[8] concerning the origin of life itself. It is pointed out that the synthesis of carbon compounds of high complexity can be carried out in consecutive stages from purely inorganic raw material by means of suitable adjustments of physical environment alone, chiefly temperature, pressure and concentration. Such laboratory synthetic products however, differ from the chemically identical products of plants and animals in being *optically inactive*. Their molecules are optically symmetrical and do not possess the molecular asymmetry of truly organic products. During a cataclysm of such magnitude as the birth of the moon, with its consequential tidal effects might there be developed an asymmetry of such terrestrial forces as gravitation, electricity, magnetism and radioactivity adequate to produce the requisite molecular distortion to enable carbon compounds of suitable composition, produced by inorganic reactions, to pass from the non-living to the vital stage? The wildness of this guess—theory it can not be called by any stretch of imagination—is fully recognized. It appears, however, from the stage of evolution attained by the earliest fossil forms preserved in the rocks, that there must have been an enormously protracted interval between the first appearance of life on the globe and its first recorded preservation in fossil form.

The epoch of formation of the first tetrahedroid tendency must be somewhat later than that of a stage of sufficient yielding of the earth's crust for the initiation of the Pacific basin, whether the latter represents a traumatic injury or not. A fundamental premise of the Tetrahedral theory is that the surface of the solid shall be fixed and not subject to elastic diminution of area as the volume decreases; or, at all events, to a diminution at a much slower rate. It is reasonable, therefore, to believe that a reasonably thick and virtually rigid crust must have developed.

It is suggested that the original Pacific depression was considerably larger than the present one, though, possibly, not so deep. If Wegener's hypothesis is correct this must be so, since he visualizes a Pacific-ward drift of *all* the lands surrounding the depression. In this, the writer thinks an error has crept in, and it is therefore suggested that the limits of the North Pacific have not altered *greatly* since its first formation. Most of the contraction in its periphery has occurred in the South Pacific, defining this sector as extending at least from the South Pole to beyond the Equator (Fig. 6).

[8] John Read, *A Textbook of Organic Chemistry: Historical, Structural, and Economic*, 2d edit., p. 353. G. Bell and Sons, Ltd. (London, 1941).

Though at the formation of the depression, the earth's crust was just weak enough to permit the scooping-out of the basin, it was on the eve of becoming so rigid that any further decrease in earth volume must initiate the tetrahedral tendency. But for the birth of the Pacific the earth body would have been sufficiently uniform and homogeneous for fairly symmetrical tetrahedroid development; but the titanic cicatrice formed by the Pacific basin threw everything out of balance—and this asymmetry is the root of the whole matter.

It is clear, when the actual distribution of continents and oceans is compared with the ideal representation of Figure 4, that much distortion must be admitted, and if possible accounted for.

In this connection it may be remarked that any deductions based on the

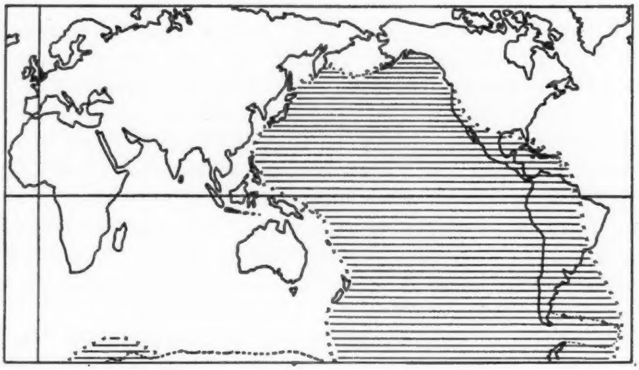


FIG. 6.—Primeval Pacific Ocean (very diagrammatic).

existing areal ratio between sea and land on the earth's surface are beside the point. Great variations in position of land and sea have occurred throughout geological history, and there is absolutely no reason to believe that the conditions prevailing at the present infinitesimal instant of cosmic time are in any way typical.

Several very conspicuous departures from symmetrical tetrahedroid form may be noted.

Firstly, the tetrahedron is inordinately elongated in the direction of the earth's axis of rotation. The Arctic shores of the continents are curiously close to 70° N. Lat. Their *general* conformity with a parallel of latitude is not unexpected as a corollary of the Tetrahedral theory; but the actual position is much too far north. This makes the Arctic Ocean much smaller than it should be. However, the Antarctic Continent also conforms rather closely to 70° S. Lat. so that it, likewise points to longitudinal extension and lateral attenuation of the tetrahedron, which actually tends to become an elevated triangular pyramid.

Secondly, there is a marked degree of discontinuity in the meridional dihedral edges, which is not apparent in the horizontal edges. This is referred to later.

Thirdly, the east-west distribution of the three northern quoins, marked by the nuclei of shield rocks, accords reasonably well with tetrahedroid development, the small discrepancies being accounted for by initial distortion due to Pacific asymmetry.

Fourthly, the overlap of Patagonia and Burma in the antipodal map must be discussed in detail.

The tetrahedrom commenced to form with one face Arctic in situation. This, and the selection of the positions of the initial quoins of the northern continental nuclei must have depended on fortuitous circumstances. There is no conceivable reason why a certain longitude should have been chosen for any one of the quoins, but, once determined, the orientation of the figure was fixed.

Once initiated, the development of the northern quoins proceeded as symmetrically as circumstances would permit, producing the nuclei of the three northern Archean shields. The injury caused by the formation of the North Pacific was sufficient to cause some distortion in the fixation of the nuclei, giving rise to the wider east-west interval between the Canadian and Asiatic shields than between the Asiatic and Fennoscandian or between the latter and the Canadian. At the same time the much more profound injury in the South Pacific region may have favored a drawing northward of the zone of continental nuclei, thus accounting for the fact that the center of this zone is 30° farther north than its theoretical position of 19½° N. Lat. This northerly distortion carries with it the relative shrinkage of the Arctic Ocean.

Matters took a far more serious turn in the South Pacific. The immense patch of scar tissue forming the ocean bottom in this region was too "pathologically" weak to take its proper part in the tetrahedroid development. Consequently, *the whole of the southern part of the tetrahedrom was congenitally deformed.* For reasons discussed later it is thought that the Pacific scar extended beyond the South Pole, and some distance into the African sector. The fourth quoin of the tetrahedron instead of developing around the South Pole was forced away from its normal position through possibly 40° in the direction of the "sound, normal tissue" formed by the Eurafrican dihedral edge, which, be it noted, is antipodal to the Pacific scar.

This distortion carried with it serious congenital spinal curvature of the three dihedral edges which should have been straight and meridional. The final result was of the general nature indicated diagrammatically in Figure 5.

A homely illustration of this kind of distortion can be seen in almost any orchard. An apple or pear, injured on one side by a hailstone or by the bite of a bird or animal, sometimes survives and repairs the wound with scar tisssue, which, however, ceased to develop normally. As the fruit continues to *expand* its healthy tissue, while the scar tissue fails to grow, the fruit becomes warped *toward* the scar, and a deformed monstrosity is produced. While, of course, there is no an-

alogy between the development of the organic matter of the fruit and that of the inorganic substance of the earth, the comparison is instructive. In the "healthy" substance of the earth, at the stage of existence postulated, development is by *contraction*, and not by expansion as with the fruit. If, then, a traumatic distortion is produced it should be *away* from the scar tissue, and not toward it as in the case of the apple.

Such a distortion may plausibly account for the initial crowding of the southern quoins and of the curvature of the dihedral angles connected with them.

Progressive cooling of the earth mass produced solidification of ever deeper shells of earth material, each such coating being successively less under the influence of the Pacific scar. The tetrahedral tendency asserted itself as each shell became thicker and stronger, setting up stresses at the roots of the continental quoins. When these stresses attained critical values the drag of the substratum prevailed over the lateral cohesion between the superficial elements and forced the continental nuclei a little nearer their ideal tetrahedral positions. Is it not possible that a general southerly shrinkage of the northern continental quoins in response to such a tendency has produced the more or less east-west tectonic axes which dominate the fold structures of these areas? Variations in solidity, in adhesion between the surface shell and the substratum and other interferences with free movement can explain local anomalies.

During the early stages of readjustment the *lateral* cohesion of the complex southern knot was sufficiently strong to resist the drag of the substratum. It is not unreasonable to suppose that the injury in the South Pacific, being so much more extensive than that in the north, affected deeper zones in the former region, so that the tetrahedral stress was less in evidence.

After the Caledonian adjustments were complete, except for minor local settlings here and there, an era of quiescence supervened, and endured for a very long period during which a still deeper earth shell developed tetrahedral stress. When at last the critical point was reached the depth and thickness of this shell were sufficient to bring about the *dehiscence* of the southern knot. Hercynian earth movements are timed correctly to initiate the dismemberment of the long-established Gondwana continent, each fragment bearing away with it the evidences of the once intimate association between them.

Again the stress spent itself, and stability was re-established.

It is necessary to hark back somewhat, and to deal with a very hypothetical possibility, but one which is believed to be worthy of close scrutiny.

For the Pacific scar to remain as a permanent feature it is essential that the sial crust torn out should have been solid enough to leave the ragged edges of the lacerated wound. It is not unreasonable to deduce that this torn edge would be subject to specially rapid chilling, and would constitute a rim of considerable strength and permanence, opposing a somewhat effective barrier to the free "draw" of material toward the Pacific. The writer is not aware that this suggestion has been advanced previously; consequently the effects of such a factor

may not have been looked for specifically and consciously in the study of the complex circum-Pacific tectonics.

Very diffidently, then, the suggestion is advanced that the complete girdle of active folding surrounding the whole of the Pacific Ocean may be regarded as something separate and distinct from the Alpine orogeny with which it is usually classed; but with which it comes into violent conflict in many critical areas.

In the North Pacific area it has been postulated already that the conditions were not such as to favor a very rapid or extensive continental drift. In late Mesozoic time, however, solidification had proceeded to a depth sufficient for the tendency toward tetrahedral adjustment to make itself apparent in this region. Both Asiatic and North American sectors moved Pacific-ward to some extent, catching the deposits of the geosynclines between the ancient shield nuclei and the resistant rampart of marginal scar tissue, thus developing what is referred to by American geologists as Laramide folding and by Russians[9] as Pacific folding. From admittedly inadequate study of the literature it appears that there are many points of difference between these structures of the folds of this era and those of the preceding Caledonian and Hercynian orogenies and of the succeeding Alpine one. Can these differences be related to the more linear and less resistant nature of the foreland opposing the thrust?

In the South Pacific conditions appear to have been different, quantitatively if not qualitatively. Of the eastern side of the basin the writer does not possess sufficiently intimate knowledge to speak with any certainty. On the western side it would appear that the rampart of scar tissue can be traced through a line joining New Caledonia and New Zealand, or possibly still farther east through the Fiji-New Zealand line. From New Zealand the line certainly runs southward to Antarctica, and it is suggested that the extremely conspicuous division of Antarctica into two units by Ross Sea on the one side and Weddell Sea on the other actually marks a fundamental structure line of enormous importance. Is it not possible that the strip from King Edward VII Land to Graham Land and the South Shetlands represents a remnant of the marginal scar tissue; while the main mass of Antarctica, including the South Pole itself, is the actual southern quoin of the tetrahedron? Certain it is that the rocks of Adelie Land in the latter sector consist largely of ancient shield gneisses and schists, strongly reminiscent of those of South and Western Australia.

On the South American side it would appear that the extraordinary loop of islands uniting Graham Land, through the South Shetland and Falkland Islands with a point on the mainland about 45° S. *may* represent the much distorted and displaced scar line of this region (Figs. 2 and 6).

On the Australian side, Australia is still a long way west of the hypothetical scar line, even though, as will be seen later, there has been rapid and extensive post-Laramide drift toward the east (or east-northeast). In Laramide time, then, though Australia unquestionably participated in the general movement, there

[9] V. A. Obruchev, *op. cit.*

was no effective foreland to produce foldings of the Rocky Mountain type. Such are conspicuously absent from the later Mesozoic formations of eastern Australia. In fact, the evidence concerning the Jurassic and Cretaceous deposits of the Great Artesian basin of Australia strongly suggests that the continent was in tension and not in compression in late Mesozoic time.

After the Laramide contraction had spent itself, apart from local adjustments, stability again reigned until Alpine stresses had accumulated in the deeper substratum. By this time the northern continental belt had become a nearly rigid ring, the dihedral edges uniting the continental quoins acting as well buttressed ribs. Nevertheless, the possibility must not be ignored of a general tendency of the entire ring to work southward toward the zone of theoretical tetrahedral symmetry in latitude $19\frac{1}{2}°$ N. The east-west foldings so conspicuous in Europe and Asia appear rather to be associated with movements of the African and Indian masses in a northerly direction.

There seems also to have been a further attempt at east-west adjustment of the gap between the Asiatic and North American nuclei, resulting in intense pinching of the sediments in the zone between the now consolidated Laramide elements and the remnants of the scar ring. The writer is inclined to regard the Japan-Aleutian Island line as an intact position of the scar ring, and therefore comparable with the New Zealand-New Caledonia (or Fiji) line in the south.

American geologists, with their intimate knowledge of the western borders of North America, will be able to differentiate many other possibilities of which the following are a few appearing to be worthy of consideration.

(1) The western part of the Coast Ranges may be the crumpled and altered sediments associated with the scar ring, and the inner folds, including, say, the Coalinga structures, may be the Alpine folds pinched between the scar ring on the west and the rigid Laramides on the east.

(2) The western advance of the continental mass may have caused complete fusion of the true Alpine folds with the scar ring, involving the latter in the former.

(3) The scar ring may have been completely overridden and lost to sight.

(4) The scar ring may be entirely a figment of the imagination; though, until the concept entered the mind of the writer recently he was always puzzled by the intensity of the foldings seen in California, in absence of any effective opposing massif to buttress them on the west.

From extremely scanty knowledge of South American tectonics it is diffidently suggested that the violent westerly drift of that continent has resulted in intense crowding and intermingling of Laramide and Alpine foldings and of scar tissue in the southern part. The extraordinary curvature of the southern tip of South America, and the apparent lag of this part in the matter of westerly drift, as compared with the movement of the broad and massive northerly sector, tempt one to advance the suggestion that both the South American and Antarctic drifting sectors actually broke through and ruptured the scar ring, carrying forward parts of it with them, involved in their Alpine folds, and leaving the inter-

mediate remnant in the form of the South Shetland-Falkland Island loop (Figs. 2 and 6).

The existence of a strikingly similar tectonic loop extending through the West Indies and Yucutan suggests a similar possibility in that region; though the intervention of the Isthmus of Panama introduces complications and difficulties which may be insuperable. At all events, the well known objective complexity of tectonic structure in the Caribbean area invites consideration of the possibility of there being *two* tectonic elements of dissimilar origin, but of superficially similar appearance entangled in the region.

The case of the Australian region appears to be rather more clear. Remembering that tectonic Australia is considerably larger than is indicated by the existing western and northern coastlines, and that it actually forms the floors of the shallow Timor and Arafura seas, one realizes that the northern edge of the Australian massif is closely pressed against the *Alpine* folds of the East Indies from Java to New Guinea, just as is peninsular India against the Himalayas and Malayan mountains. The titanic mountain development of the Himalayan group is readily accounted for by the extremely efficient vice constituted by the plunging mass of peninsular India on the one hand, and the immovable Siberian mass on the other.

Although the plunging Australian mass may be even larger than the Indian one, and although its velocity of movement may be even greater, the absence of any effective buttress has enabled it to drive its "bow-wave" forward without uplifting the folds into high mountain ranges.

That New Guinea belongs to the main Alpine system is unquestionable. The impact of Australia has broken the back of this very massive island unit, and caused the kink near the international boundary line. Australia itself did not come off scatheless in the encounter, as the local distortion of Cretaceous sediments in the Broadsound area of Queensland suggests. This explanation appears preferable to regarding the folds in question as very local manifestations of Laramide activity.

North and east of New Guinea, however, the tectonic structure becomes extraordinarily complicated. While there is no such conspicuously marked loop line here as those of the South Shetlands and West Indies the confusion of axial structural lines is even greater. There can be little doubt that the New Ireland—Solomon Island axis belongs to the scar line, but there is an inextricable tangle of intersections. Again it is suggested that if the concept of a fundamentally distinct and relatively ancient circum-Pacific scar line is tenable it is capable of providing a key which ultimately may assist in resolving the tangle.

One is tempted to embark upon still other explorations of possibilities inherent in these ideas. Thus, it seems clear that peninsular India, though obviously one of the fragments of Gondwana land, has embarked on a career different from those pursued by the other three major sectors. In drifting directly into the main-

land of continental Asia it has plowed its way through the deep geosyncline, which, from the earliest dawn of earth history, separated the Asiatic and Fennoscandian continental nuclei. Again it must be emphasised that the Caspian, Turkestan, Persian Gulf sector, while now well within the limits of the land area of Asia, was, functionally, throughout geological history the northern part of the Indian Ocean. Much of the mightiest mountain mass on earth is situated where India has plunged in among the deposits of this deep geosyncline, and driven them before it in its endeavors to reach its allotted station as part of the Asiatic-Australian dihedral edge. In this endeavor it has been frustrated by the stupendous mechanical work of building up the mountain masses. While Australia is reasonably close to the line which one may suppose it should eventually occupy in the complete tetrahedral symmetry, India still lags at least 40° behind.

Clear as it is that Australia has drifted east or east-northeast until it has squeezed New Guinea against the scar line of the Pacific, the absence of any pronounced Laramide and Alpine foldings in continental Australia suggests that, throughout most of its long journey of drift, it has had an unobstructed course. If it is correct that, once the approximate tetrahedral symmetry is restored, the impulse toward continental drift will come to an end, the wanderings of Australia may be almost finished. That this may be the case is at least suggested by the contours of the ocean floor in the New Zealand-Kermadec Island area. Along this line there exist some of the deepest chasms in the ocean bottom. Their form and direction strongly suggest that they are the result of tensional stress rather than compression. If this be so, it follows that, instead of there being a tendency for the Australian mass to continue its career Pacific-ward, the scar line in this sector is actually being caught up in the tetrahedral readjustment, and is being drawn west to help to build up the outer part of the Asiatic-Australian dihedral edge.

It is to be noted that a similar tendency may be present in the North Pacific, where, also, abyssal oceanic depths form a line parallel with the coasts of Japan.

The Antarctic Continent, like Australia, seems to have reached its final resting place. Probably, like Australia, it never encountered resistance enough to give rise to excessive mountain foldings, though, if it is correct that it has impinged on and broken through the scar line in the South Shetlands area, this may have to be modified.

South America, like India, has failed to arrive at its logical destination, which should bring the oldlands of Brazil south of the Canadian shield. It has been suggested above that its westerly drift has been hindered very considerably by the presence of a strong part of the scar ring around what was the southeastern edge of the Pacific depression. At all events, South America as a whole is about 40° too far east to play its proper part in the development of ideal tetrahedral symmetry. It should be noted that if South America had come into meridional relation with the Canadian quoin, the overlap in the antipodal map (Fig. 1)

would bring Patagonia into the Turkestan-Caspian triangle, which, as already stated, is functionally the northern extension of the Indian Ocean. The fault of the asymmetry in this pattern rests with South America.

An objective fact of major importance which is not included in the list on a subsequent page, and for which an immediate explanation is not forthcoming, is the existence of a break in continuity of the meridional ribs of the fundamental tetrahedron composed of ancient shield formations. Theoretically the dihedral edges of the continental nuclei should be composed of such formations, and should be buttresses of great solidity and permanence. On the earth we find that, in every instance, such buttressed ribs are conspicuous by their absence from the sector between the northern quoins and the southern apices of the triangular continental nuclei.

Moreover, there appears to be no evidence whatever of even a remnant of their presence in such situations, even at the inception of tetrahedroid development. The broad zone stretching through the Antillean area, the Mediterranean, and sweeping down through the Persian and Turkestan regions to and through the East Indies (neglecting peninsular India, which may be regarded as a trespassing unit), appears to have been a permanent geosynclinal sector throughout geological time, a role which it continues to play to a more or less marked degree.

Is there any conceivable reason why such a zone of weakness should develop and persist during tetrahedroid deformation?

It may be mentioned, though very little importance is attached to the particular observation, that, during the writer's very early and crude experiments with steam-filled metal spheres, there was in one case collapse of the figure and crumpling of the meridional edges, more or less reminiscent of the type of weakness here visualized. The test was quite inconclusive, since the sphere in question was built up of lunes of thin metal, dished and curved, and soldered along the edges. There was therefore an entire absence of even the semblance of homogeneity of structure which must be postulated for the earth body.

Possibly mathematical investigation may show that the tetrahedral quoins, consisting of the three dihedral edges converging to a point, may form mechanically sound and rigid structures which refuse to become distorted; while the single dihedral edge uniting any two adjacent quoins *may* be mechanically weaker, and prone to collapse. If such a tendency exists it would certainly be accentuated by the axial attenuation of the figure which converts it into an elongated triangular pyramid.

Even without attenuation, however, the fact is that the three northern dihedral edges, lying in a plane of rotation, would be stressed differently from the meridional dihedral edges, which are transverse to the direction of rotation. This *may* be why the latter edges show weakness while the former do not.

In this connection it may be pointed out that the tidal effects must have been much more powerful in the earliest stages of tetrahedroid development, while the mass of the earth was still far less consolidated than it became later. If, as Dar-

win's results seem to indicate, the moon's distance at that epoch was far less than it is now, tidal stresses alone may have been adequate to produce the weakness.

One is tempted to explore the possibility of a centrifuge effect due to earth rotation; but an angular velocity of only 15 seconds of arc per second of time appears totally inadequate to produce such a result. The angular velocity in a cream separator necessary to separate butter fat from water is many thousands of times as great. Is it possible that, infinitesimal as is the centrifugal effect of earth rotation, it may be integrated to attain a finite value in the course of what is potentially infinite time? Moreover it is certain that diurnal rotation was originally much higher than it is now, though it is inconceivable that it ever approximated to that of a mechanical centrifuge.

If a centrifugal effect is admissible, the result must be visible in the thinning of the sial crust toward the Equator, and the bringing of the underlying sima layer closer to the surface. This should be indicated by systematic variations in the compositions of igneous rocks, particularly volcanic ones, in the equatorial zone; a variation which, so far as is known, has not been established.

One last possibility must be mentioned. The belt of weakness is not exactly equatorial; it is farther north in the Eurafrican sector, antipodal to the Pacific, than it is in the Pacific area. As the line approaches the Pacific it actually passes into south latitude. Is it possible that the zone *was* actually equatorial at the date of the moon separation (on Darwin's hypothesis), and that some minor irregularity in the separation of the moon mass threw the earth figure into a state of unbalance, necessitating a slight adjustment of the axis of rotation?

This speculation—admittedly a very long-range shot—would fit in quite neatly with the apparently objective fact that the earth lesion caused by the South Pacific seems to have been considerably more severe than that of the North Pacific; a possibility which has been evoked already to account for the assumed congenital deformity of the tetrahedron.

If the results of the foregoing discussion are accepted, even in broad principle, they may apparently contribute to some of the other geophysical difficulties which have long been stumbling blocks in the domain of geological theory. One of these outstanding difficulties is that of accounting for the energy relations exhibited by the periodically recurring eras of orogenesis. These movements involve vast expenditure of dynamical force to produce the mechanical deformations observed, and probably even greater amounts of energy in the form of heat and molecular condensation essential to account for the igneous injections and rock metamorphism so intimately associated with mountain building.

If the primary speculation of early asymmetry rests on firm foundations—and the malformation of the Pacific Ocean is an unquestionable fact which must be explained somehow—the remaining links in the chain form a logical sequence. It has always appeared to the writer, that, convincing as was the evidence for the Wegenerian hypothesis as applied to the southern continents, it lacked the motive force necessary for its realization.

Initial traumatic deformity engendered in an attempt to produce tetrahedroid symmetry, followed by the re-assertion of the symmetrical tendency as deeper zones, unaffected by the surface injury, exerted their stress upon the deep-seated roots of the continental nuclei, makes available at once a reason and a supply of energy adequate to account for continental movement, for recurrent diastrophisms, for igneous injections even if they involve extensive melting of great masses of sediment, and for the processes of metamorphism.

The not unreasonable suggestion of the long-enduring existence of a circum-Pacific scar may provide an escape from the dilemma caused by the extreme complexity of the tectonic features of such critical regions as the East and West Indies and Cape Horn.

It is not considered for a moment that these factors are the only ones involved, and that they are exclusive of the many other causes which have been adduced to account for the major phases of dynamical geology. Unquestionably the energy effects of radioactivity must play a very important role in all such processes. In fact, there seems a very high probability that there still remain unconsidered effects in geophysical history which, when glimpsed, will provide short cuts to the understanding of terrestrial embryology.

The well debated effects of sedimentation in geosynclines, redistribution of geoisotherms, and many others, unquestionably contribute to the ultimate integration of geodynamical efficiency.

CONCLUSIONS

The sole justifications for excursions, such as the present one, into the realms of pure speculation in geology is that the conclusions arrived at should not be inadmissible within the limits of the fundamental laws of physics, chemistry, and mathematics which ultimately control all the phenomena of non-living matter. It is essential also that the suggestions made should direct the attention of scientific investigators to the phenomena which are under observation by them. In a scientific investigation it always happens that there are details which appear trivial or extraneous when viewed only from the conventional standpoint. When, however, special attention is focussed on them owing to a suggested change in the point of view it is often found that such details assume and importance and a perspective not previously realized.

It is therefore suggested that investigators engaged in the study of major tectonic problems everywhere, but particularly in circum-Pacific areas, should give some special thought to the possibilities here advanced. If it is found that the suggestions are in conflict with objective fact they will be permanently eliminated, and need not again be considered by those who are delving into ultimate mysteries. If, on the other hand, phenomena otherwise unrelated become co-ordinated, the crude speculations here advanced can be modified and shaped more accurately to portray the real facts.

It is especially suggested that investigators should test critically the possibility of the existence of a circum-Pacific fundamental structure in relation to

the conflict between Alpine folds and those circum-Pacific folds which intersect them so conspicuously in the East and West Indies, and possibly in the Cape Horn region.

A second "long-range" objective may possibly exist in relation to the nature and origin of the broad belt of long-persisting earth weakness breaking across the meridional continuity of the main ancient shield areas, generally a little north of the Equator. In this connection the bare possibility should be canvassed of the

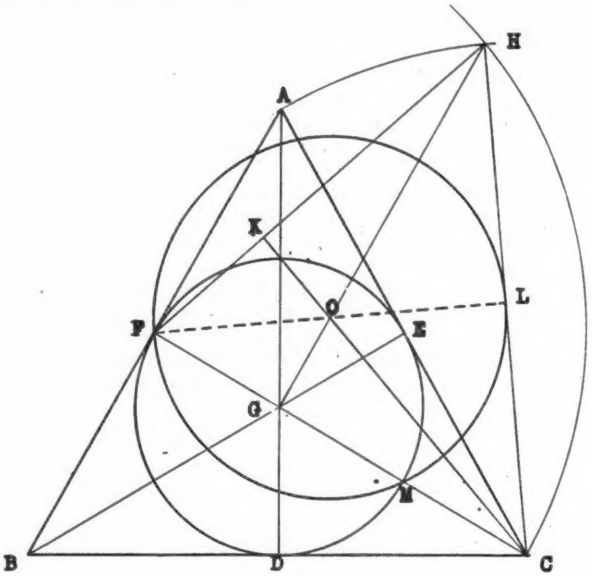


FIG. 7.—Geometry of tetrahedron and sphere.

existence of a centrifuge effect, bringing about an equatorial thinning of the sial envelope, and a decrease in depth from the surface of the upper boundary of the underlying sima.

If there is any semblance of reason in the speculations it appears that there should be scope for mathematical treatment of the possibilities and consequences of initial Pacific distortion, tetrahedroid development, congenital deformity of the tetrahedroid figure, its dehiscence during Hercynian time, continental drift, and the release of latent kinetic energy thereby. Mathematical analysis of the effects of tidal retardation on a tetrahedroid figure rotating about one of its trial axes of symmetry may be found to be a profitable exercise.

SUPPLEMENTARY NOTE. GEOMETRY OF TETRAHEDRON

Figure 7 provides the data for the case of a tetrahedron and sphere in equipoise. as illustrated in Figures 3 and 4.

ABC is the horizontal, north polar face of the tetrahedron, *G* being the central point of the equilateral triangle.

CFH is the central vertical plane of the tetrahedron rabetted round the common section *CF* into the plane of the drawing; so that *H* is the south polar quoin of the figure. This shows that *O* is the common center of the figure. *O*, of course, lies vertically below *G* in the three-dimensional figure.

A sphere with center *O* and radius $OF = OL$ touches all the dihedral edges of the tetrahedron at their middle points, that is, passes through the ends of the cubic axes.

In the three-dimensional figure the light circle with *O* as center and *OF* as radius is in the vertical plane at right angles to the plane of *ABC; FGM* is the common section of the circle and plane. Since the section of a sphere by a plane is a circle, therefore, the heavy circle with *G* as center and *GF* as radius is the trace of the sphere on the horizontal face of the tetrahedron, that is, is the outline of the "Arctic Ocean" of the figure. The triangular areas with curved edges *AFE, BDF, CED,* are the projecting portions of the three "continents" involving the face *ABC* of the tetrahedron. These "continents" just touch one another at the angular points of three basal curved triangles, at the points of emergence of the cubic axes.

The angle GOK = the internormal angle between adjacent tetrahedral faces, by calculation $109° 28'$. This is equal to the arc of the great circle of the sphere between the South Pole and any one of the remaining quoins, so that the latter lie on the small circle of $19\frac{1}{2}°$ N. Lat.

The angle OFG = latitude of the face *ABC*. By calculation this is $35°16'$ N. Lat.

Since the southern extremities of the northern "continents" are midway between their own centers and the center of the "Antarctic Continent," they reach Lat. $35°16'$ S.

Under these conditions the area of each of the oceans is one sixth of the area of the surface of the sphere, or the four oceans occupy two thirds of the surface, and the continents one third.

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RECENT TRENDS IN GEOLOGICAL-GEOPHYSICAL EXPLORATION AND METHODS OF IMPROVING USE OF GEOPHYSICAL DATA[1]

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ABSTRACT

Since 1942 the use of gravimetric methods has increased in the United States approximately 200 per cent, seismic methods 50 per cent, core drilling 100 per cent, and the magnetic investigations 70 per cent. The impact upon geological thinking because of this continued increase of geophysical effort is discussed. Full advantage offered by these methods and combinations of methods is not being made. A better use of the low-cost methods is pointed out. With the tremendous increase in the use of the gravity method there has not been a corresponding improvement in the proper understanding of its possible use and its limitations. The gravity method is discussed in some detail. A tremendous improvement in our geological thinking and a better use of geophysical data are possible by an education of "district" or "grass-root" geologists in geophysical concepts and a freer use of this information. A trend in this direction is noted, but the need of an accelerated move in this trend is emphasized.

INTRODUCTION

The geological staffs of oil companies were so depleted during the war that a minimum of work was devoted to the development of new geological ideas. The need of new reserves was never greater and extra effort was put forth to make new discoveries; but this special effort included not new procedures but a greatly increased use of existing techniques, with expenditures in geophysical exploration greatly increased, as the following figures show.

Approximately 150 gravity meters were in operation on oil exploration in the United States in November, 1945, an increase of 200 per cent over the activity of 1942. During this same period the seismic units increased to 324 (a 50 per cent rise), core drills to 52 units (a 100 per cent increase), and magnetic exploration 18 units (a 70 per cent increase). In fact, the geophysical exploration in some areas was limited only by available men and equipment. A noticeable decrease in geophysical exploration is recorded in the first 3 months of 1946, but this exploration effort probably will remain at approximately its present high level through the present year.

In passing, it is of interest to record that similar exploration increased tremendously in Mexico and South America during a similar period. Three service companies offering seismic and gravimetric exploration in foreign lands offer an index to this increased activity. This group alone reported a total of three seismic units and one gravity-meter unit in operation in Mexico and South America in 1942, and 21 seismic units and 10 gravity meters operating in 1945. This activity represents approximately 30 per cent of the geophysical exploration being conducted in these countries.

[1] Read before the Association at Chicago, April 4, 1946. Manuscript received, June 10, 1946. Published by permission of Stanolind Oil and Gas Company.

[2] Geophysical coordinator, Stanolind Oil and Gas Company. The writer is indebted to G. L. Taylor and W. R. Sype for the computations used and for helpful suggestions. For the numerous drawings, he is indebted to several members of the geophysical and geological staffs.

The development of an air-borne magnetometer for war purposes and its adaptation to general magnetic mapping is a revolutionary advance. The use of such equipment will stimulate magnetic exploration generally and make feasible the investigation of aseas not accessible by ordinary means of travel.

Other geophysical activity at the beginning of 1946 includes four companies offering soil-gas analysis and one analyzing the fluorescence of soil samples as a means of exploring for petroleum direct. At least two companies report the use of electrical methods during the period.

Although there were few new developments in geological methods during this period, some progress can be reported in the application of old techniques to new problems. The renewed interest in the Rocky Mountain states brought many geologists to this province to do surface mapping and thus restore an art all but lost to our profession. The use of insoluble residues in the pre-Permian beds of West Texas has been successful in breaking down the Ellenburger formation into several recognizable units. Improved methods of logging shallow core holes by electrical methods have made core drilling feasible in areas which formerly could not be economically explored because of the lack of recognizable shallow markers. New logging services include new procedures and improvements in the quality of data provided by established methods. Gamma-ray logging has become an accepted practice in some areas. A method of determining dips in drilling wells by electrical methods was perfected and made available to the industry in 1943 and radioactive bullet markers used in 1944 assisted geologists in making precise the location of pay sands in deep wells. Seismic and gravity methods were adapted to work in the open ocean during the war period, and exploration of parts of the Gulf of Mexico is now under way.

Studies neglected in recent years include the origin of sands, analysis of waters and studies of temperature gradients. The geologist who undertakes any of these special studies finds himself at a disadvantage because of the lack of material in the provinces best suited for investigation. The question then arises as to the limits we should go beyond those generally imposed on a drilling well to obtain data on all formations drilled. Every wildcat well is a research project and within certain limits should be so treated. The idea suggests itself that some cooperative scheme be initiated whereby information be obtained from all wells drilled within a selected area and thus provide data from numerous strata, making possible exhaustive geological research. The problem invites discussion not possible in this paper.

An examination of our geological and geophysical expenditures will focus attention on that part of our exploration effort which is of maximum concern. The exploration budgets of at least three companies whose geological and geophysical expense exceeds $5,000,000 yearly carry items for geophysical expense in excess of total geological expense in ratios ranging between 5 to 1 and 10 to 1. Obviously, the geophysical expenditures which have continually increased for the past 10 years will remain, and properly so, at a high level indefinitely.

Analyzing the results of this tremendous effort in acquiring new data of use to the geologist, we should have cause to wonder how exhaustively this information is being used. Little, if any, geophysical data can be analyzed to the point where the original interpretation can be made, conclusions drawn, and the geophysical records put aside. The problem becomes stupendous when we realize that almost any well drilled necessitates a reconsideration and a re-study of the original data; in fact, the geophysical data in some areas require a certain amount of exploration by drilling before an intelligent interpretation can be made.

The purpose of this paper is to inquire into certain phases of the progress of geological thinking during this period in which geophysical expenditures have grown to such high levels. Have we been sufficiently alert to the advantages offered by the tremendous acceleration in the rate of supplying data to the geologist? From such an analysis we see the need of a definite trend in geological procedure and thinking to maintain a well balanced exploration program.

We have been continually asking for an exploration method by which to explore for petroleum direct. Certain methods working to this end have not yet reached the stage where they are satisfactory. Until a direct method completely satisfactory is developed, the geologist is challenged to make better use of the things now at his command.

At the risk of being considered out of place in presenting these ideas before a geological group, rather than before a geophysical group, and at the risk of being considered elementary, the writer presents certain phases of geological-geophysical thinking which may seem trite but which, however, are fundamental. Such a repetition will attempt to prove that the geologist must have a better understanding of geophysical concepts if he is to make better use of existing information.

To project geological interpretation beyond the initial and apparently obvious interpretations made by the geophysicist at the completion of this original work involves geological thinking of the highest order. To construct a map from the initial seismic data, or to draw circles on gravity maps outlining anomalies, is only the beginning of geophysical interpretation. The geological aspects of only those phases of geophysical-geological interpretation which have not received their proper attention will be discussed.

COORDINATION OF GEOPHYSICAL EXPLORATION

No geophysical surveys employing the commonly used devices fail to contribute data by which the geology of an area may be better understood. The question may be asked, "Does the information contribute enough to be worth the cost of obtaining it?"

Any contemplated program of geophysical exploration involving one or more methods must be based on the general approximation that a gravity survey costs per unit area ten times that of a magnetic survey, and a seismic survey ten times that of a gravity survey. The cost of core drilling ranges so much that no figure

can be given which would be meaningful in this cost schedule. In general, it is more expensive per unit area explored than other methods and should be used only in special cases where other methods have failed.

If the geophysical characteristics of an area lend themselves to exploration by low cost methods, a progressive order of work from the less expensive to the more costly can be used with distinct advantage in the ultimate cost of the work. Frequently a consideration of more importance than the ultimate cost is the timing of the exploration effort and the speed with which information is made available by the low cost methods. The question of which technique is best suited for any given area may require a trial, but within certain limits the effectiveness of some methods can be predicted; this will be discussed later.

Rightly used, a series of geophysical surveys from the less costly to the more costly will progressively narrow the area of interest. Under such a program the value of any one survey is difficult, if not impossible, to determine—all combine in producing a finished product.

The writer takes violent exception to the thought implied in many analyses of exploratory effort, wherein a series of discoveries is listed the the methods responsible for each discovery. If these analyses reflect accurately the methods employed, it is evident that the geologist frequently is not using the several geophysical techniques in proper coordination. Under ideal conditions the several methods should not be used competitively but each should contribute an essential part in the program. A simple statement of an actual case serves to illustrate the point.

A magnetically anomalous trend supported by a limited gravity survey provided the incentive in leasing a 50,000-acre block so far ahead of the exploration for the area that the cost per acre was one-fifth the going price for wildcat acreage being paid in neighboring counties. Core drilling followed in two selected areas in the block. In one area a map of a shallow marker was sufficiently interesting to justify a well which discovered a new field. An anomalous picture was obtained in the second area by core drilling. A limited amount of seismic work was then completed, a second well located, and a second field discovered.

The area involved parts of Barton County, Kansas, and the two pools discovered were the Richardson and South Ellinwood. The original cost of the block was 10 cents per acre and the over-all time from the beginning of the work to the time when the second prospect was ready for drilling was one year. The records mention that one pool was discovered by core drilling and the second by seismic methods—what an injustice to the exploration effort!

The fact that additional oil pools have been since discovered in the area covered by the original surveys but not predicted by the original work does not detract from the methods or from the coordination employed. The original discoveries provide the geological characteristics of the area and the focal points from which further exploration could be planned in an orderly manner at a minimum expense.

The simultaneous interpretation of two or more sets of geophysical data has

many obvious advantages. Special advantages of such a procedure are found in areas where the data from any one method are inferior in grade, or the results inconclusive. In making interpretations of several sets of data, it is vital to have well in mind the probable geological circumstances responsible for each. Under such conditions two sets of geophysical data can be made to complement each other.

Magnetic and gravity exploration in West Texas and adjoining New Mexico are both effective, but for different reasons. The magnetic disturbances are related to the structural features of pre-Cambrian rocks, and the local gravity anomalies are due largely to the density contrasts between the redbeds section and its associated salt with the "lime" below—two horizons which may be several thousand feet apart.

The mapping of the surface formations is justified even where the information itself does not have impressive significance, but when taken with an adequate gravity survey may be of much value. A single isolated outcrop of pre-Tertiary beds in the Tertiary-covered areas of the Rocky Mountains may be of inestimable value in helping in the interpretation of a regional gravity map. A few strategically placed core holes, or a single seismic traverse of limited extent with a regional gravity survey may serve the same purpose of predicting the general structural picture which can be further explored in an orderly and well planned manner with a minimum of expense.

In dealing with several sets of geophysical data, each inadequate in itself to provide a solution to the problem, the geologist is faced with the same problem confronting a doctor in diagnosing an ailment. Two different symptoms are many times more valuable in drawing the proper conclusion than one, and three are better than two. The sum total of the value of these clues may not be an algebraic sum but some larger value.

A series of marginal seismograph traverses obtained in an area where salt domes are expected may be combined with an inconclusive gravity survey to suggest whether or not a salt intrusion is to be expected. Again, a marginal seismic survey can often be combined with a marginal gravity survey to change an area of questionable value into one having a third- or second-class rating which demands further exploration.

Many instances have been noted where complete gravity surveys have outlined the presence of deep-seated features which the original seismic exploration failed to find because of inadequate exploration. Under such conditions special effort and special techniques should be employed to give proper attention to the area. Let us examine two areas where two or more sets of data can be used to the mutual benefit of both methods.

The outlining of two gravity anomalies in Figure 1-A is clearly justified at points *A* and *B*. Subsequent exploration has shown both to be structurally of interest. A magnetic map (Fig. 1-B) of the same area outlines a magnetic anomaly at *A* but none at *B*. Inasmuch as structure of the limestone strata at 4000 feet is

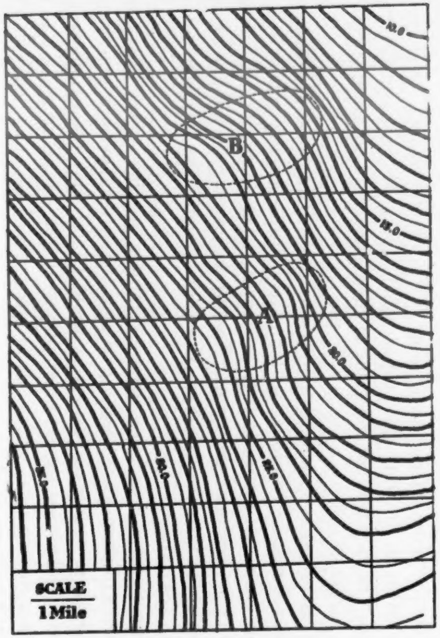

FIG. 1-A.—Gravity contours of area in West Texas; Contour interval 0.5 milligal. Anomalies at *A* and *B* produced largely by density contrasts between redbeds and limestone at depth of approximately 4,000 feet. Both anomalies outline known structures.

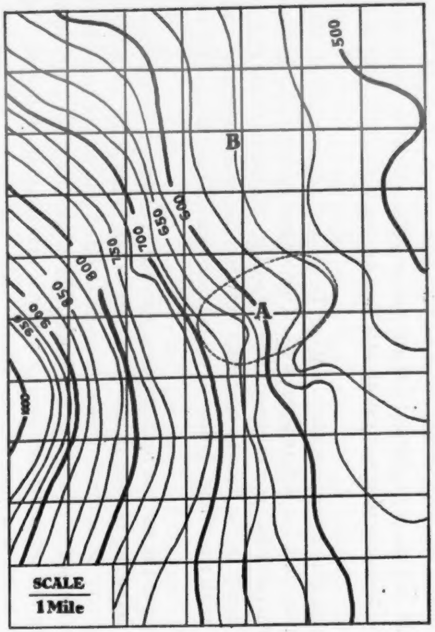

FIG. 1-B.—Magnetic contours of area in West Texas; outlined in Figure 1-A. Contour interval, 25 gammas. Note magnetic anomaly at *A* and absence of any at *B*. Pre-Cambrian formation which produces this anomaly is known to be 3,000 feet deeper at *B* than at *A*.

responsible for the gravity anomalies and the pre-Cambrian formations are responsible for the magnetic effects, it follows that the pre-Cambrian is much deeper under structure *B* than at *A*. This conclusion has been confirmed by drilling which places the pre-Cambrian more than 3,000 feet deeper at *B* than at *A*.

A prominent gravity anomaly in a Tertiary-covered area is outlined in Figure 2. The area is characterized by much pre-Tertiary topography which permits the

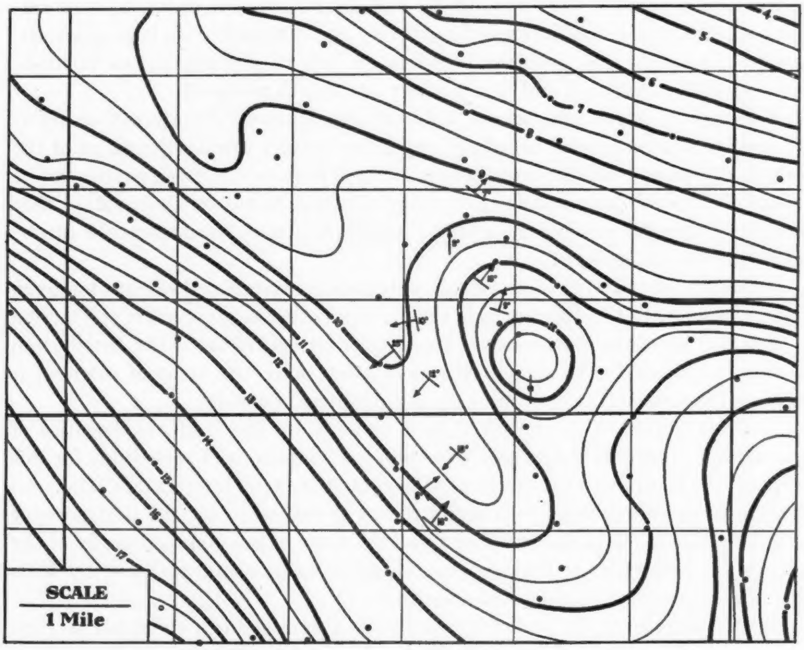

FIG. 2.—Gravity anomaly in Tertiary-covered area of Rocky Mountains; contour interval, 0.5 milligal. Area characterized by pre-Tertiary structure and topography either of which might produce anomaly. Dips from limited seismic exploration confirm presence of shallow structure rather than pre-Tertiary topography.

possibility that the gravity meter mapped only topography. A few well placed seismic dips eliminate this possibility. Again, the shape of the gravity anomaly indicates the beds providing the density contrasts are shallow. The feature was explored by a core drill hole less than 2,500 feet deep.

GRAVITY SURVEYS AND THEIR INTERPRETATION

The unprecedented increase in the use of the gravity meter in the last 4 years calls for a critical study as to the methods of conducting these surveys and the

interpretation of the data. This type of exploration will doubtless repeat the mistakes of seismic exploration where conclusions were made erroneously with inadequate control and too little, or no, attention was paid to anomalous data just because we thought them incorrect.

Emphasis is given to the discussion of the low-cost geophysical methods not because they are the most important—they are not—but because the data provided by these methods have been so mistreated and so misunderstood that an explanation of some of their possibilities and limitations is in order. Up to a certain point the problem of interpreting gravity and magnetic data is geophysical; beyond this point the problem becomes geological, demanding an intimate knowledge of the regional and local geology of the area involved.

Although it is true that several different distributions of materials of different density can be devised to satisfy any given gravity profile, the range of the geologically acceptable circumstances which will provide the given profile can be limited. It is possible to restrict this range of probable answers well within that commonly thought possible by a proper application of techniques which can be developed by the geologist.

Although the gravity meter measures the total gravitational effects at a given point, those due to the differences in the densities of rocks involved in the section to be drilled are of the most concern. Inasmuch as irregularities in the distribution of these densities due to structural deformation mark the areas of interest, it becomes fundamental to determine these differences in density.

A direct approach to the problem is possible by the study of densities of cuttings and cores. Much has been said as to the limitations of such study for this purpose; the fact remains it can be used to contribute vital information. The need of such an extended study in a regional way is necessary for the best possible understanding of the problem. After 3 years of more or less constant study of the density characteristics of cuttings, cores, and outcrop samples, the writer finds that new data are continually full of surprises.

With a knowledge of the density contrasts determined in a columnar section, the gravity effect of any part, or all, of the sedimentary section can be determined in any given structural deformation. Given the problem of exploring any area, the computed effect of the minimum-sized structure of interest can be determined. If the computed effect is measurable by a gravity meter, the problem becomes workable if a pattern of observations suitable for detection of such a structure is selected.

Fortunately, the whole scheme is subject to a fairly rigid test. The gravity anomaly of a known structure well controlled by subsurface data can be computed from the density data at hand and checked against an actual field survey. If the comparison is proved satisfactory, confidence is established in the method and the possibilities of using the gravity meter effectively. Measured by such standards numerous gravity surveys fall far short of accomplishing the thing they were designed to do.

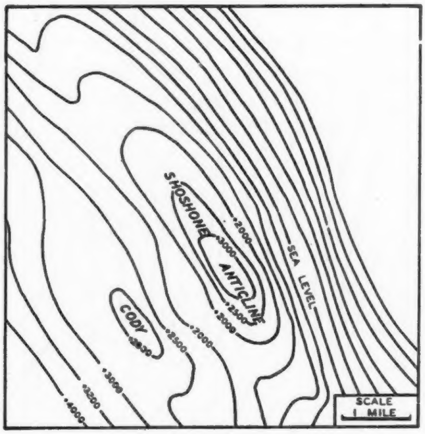

FIG. 3-A.—Structure of Shoshone and Cody anticlines, Park County, Wyoming, Contours on top of Cloverly group. Interval 500 feet.

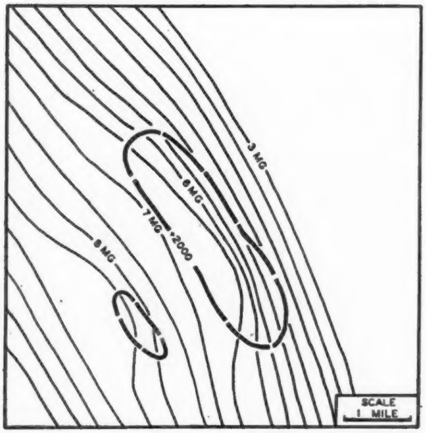

FIG. 3-B.—Gravity anomaly computed from structure outlined in Figure 3-A. Contour interval, 0.5 milligal. Heavy lines outline position of structures.

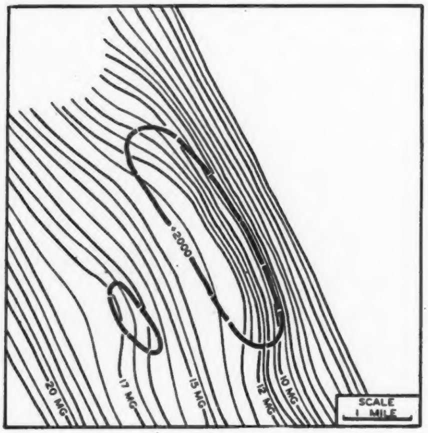

FIG. 3-C.—Gravity anomaly of Figure 3-B with regional gradient added.

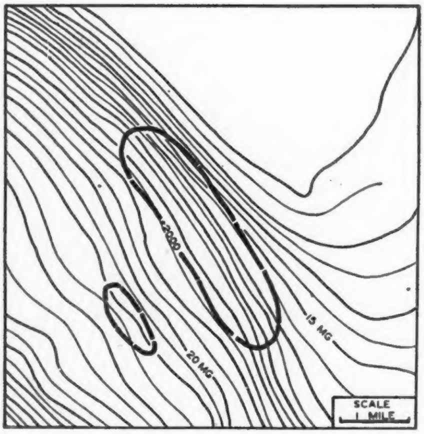

FIG. 3-D.—Observed gravity of structures outlined in Figure 3-A. Agreement between Figure 3-C and D is fair. Inaccuracy in original structural map may account for some of these differences.

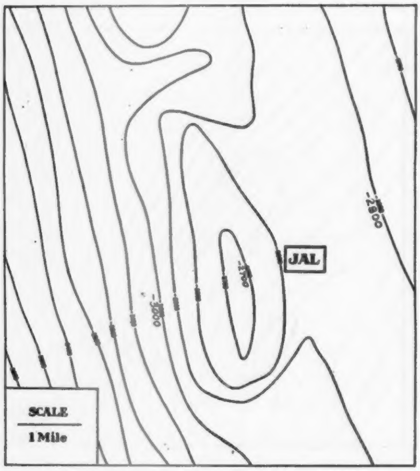

FIG. 4-A.—Structure on top of San Andres in vicinity of Jal, Lea County, New Mexico.

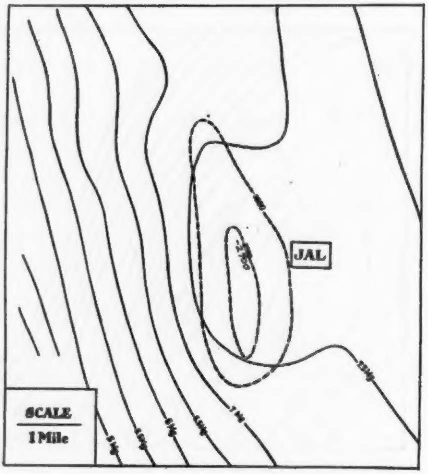

FIG. 4-B.—Gravity anomaly computed from structure of Figure 4-A. Contour interval, 0.5 milligal. Dashed lines from San Andres structure.

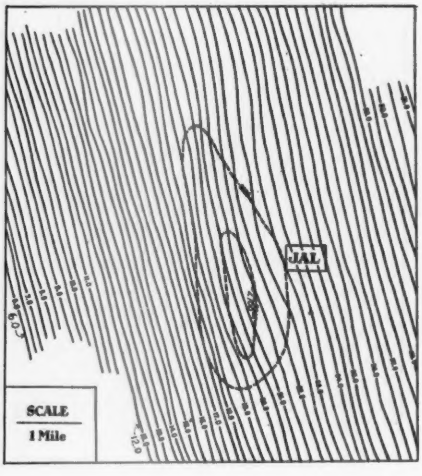

FIG. 4-C.—Gravity anomaly of Figure 4-A with regional gradient added.

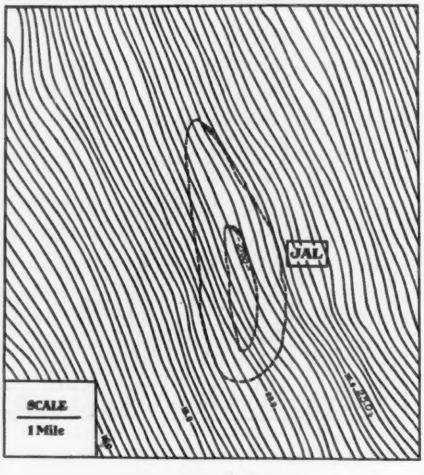

FIG. 4-D.—Observed gravity of area covered by Figure 4-A. Comparison with Figure 4-C shows similarity of anomalies immediately west of village of Jal. Need of carefully planned survey in such areas is apparent.

Two areas have been selected to illustrate the analysis outlined. The Shoshone anticline in Park County, Wyoming, having structural relief of 1,000 feet and a width of one mile, produces an anomaly of 3 milligals which is readily recognized. A marginal structure in the vicinity of Jal, Lea County, New Mexico, produces an anomaly of 0.3 milligal, which can he detected in the strong regional gradient of the area only by a well planned and carefully executed gravity survey.

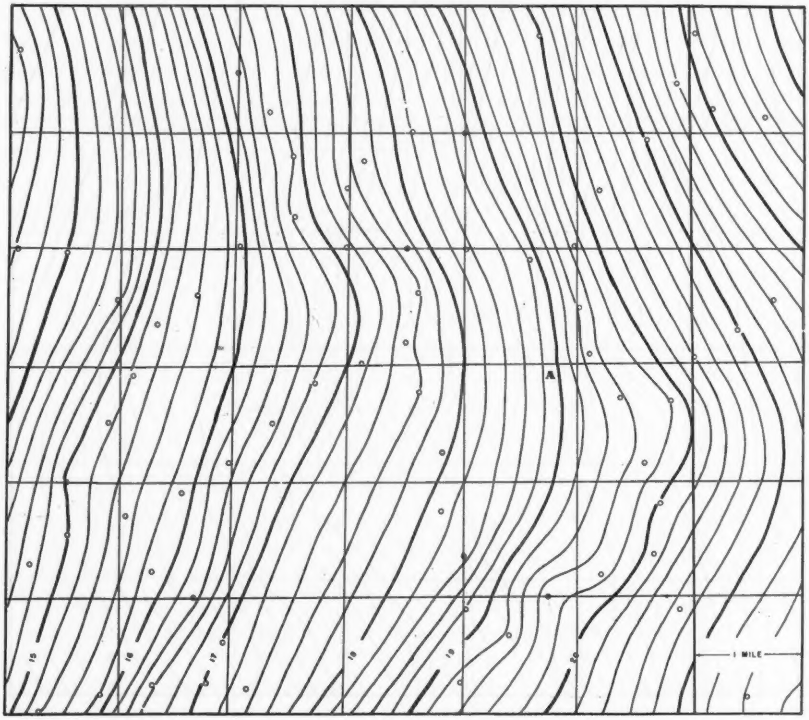

FIG. 5-A.—Gravity contours from reconnaissance survey of area in Mississippi. Salt dome is suspected in vicinity of *A*. Location of observations indicated by circles; contour interval, 0.2 milligal.

The Shoshone anticline is outlined in Figure 3-A, which with the densities of the formations involved permits the determination of the gravity effect at as many points as desired. Figure 3-B, resulting from such a computation, outlines the gravity effects of the structure only. To these effects has been added a regional gradient determined by study of the regional gravity map. Figure 3-C outlines this combination which can be compared with the observed gravity Figure 3-D. The two maps agree that the total anomaly is approximately 3 milligals. The

greater length of the anomaly outlined by the observed gravity is due to the inaccuracies of the original structural map and an inadequate number of stations computed.

Figure 4-A outlines a small structure on the top of the "lime" in the vicinity of Jal. The computed anomaly is mapped on Figure 4-B. In order to make a com-

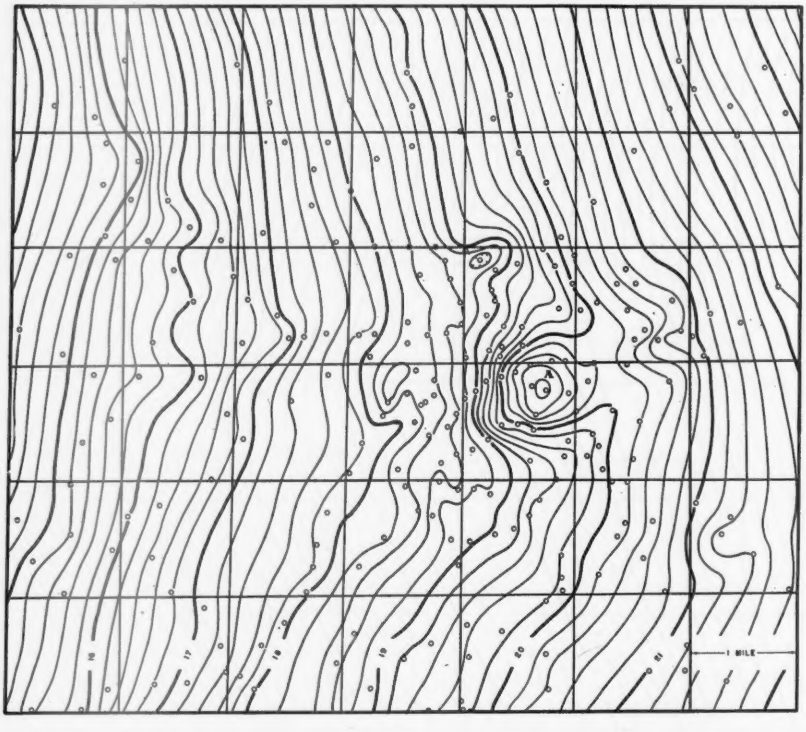

FIG. 5-B.—Gravity contours from detailed survey of area shown in Figure 5-A. Evidence of "caprock" indicates piercement salt dome confirmed by subsequent drilling. Note observations indicating presence of "cap" limited to one square mile.

parison with the observed gravity Figure 4-D, it becomes necessary to add to the local anomaly a regional gradient; this combination is shown in Figure 4-C. A comparison of Figure 4-C and Figure 4-D shows the similarity of the anomaly immediately west of Jal. A survey capable of detecting this structure need be planned with care. The anomaly noted southeast of Jal on the observed gravity map is the expression of a second structural feature in this vicinity which was not considered in the calculated gravity effects of the Jal structure.

Many surveys are inadequately controlled and thus fail where they should

succeed marvelously. One typical example is outlined (Fig. 5-A) where a casual survey suggested an anomaly which could be outlined in a general way by the original investigation. The presence of the "caprock" of a piercement salt dome was apparent only after a detailed survey (Fig. 5-B). The need of the dense pattern of observations is obvious by comparing the two maps. The observations revealing the presence of the "cap" are confined to approximately one square mile.

Few gravity surveys can be properly completed without an intimate knowledge of the geology of the surface formation. Different formations at outcrop generally require a change in density factors used and the limitations of probable error in terrane correction and other near-surface effects are better understood by field observations. Such information is obtained best in the field by a geologist who understands the geophysical problem.

A further analysis of gravity interpretation includes a brief discussion of important phases of the problem.

DIRECT INTERPRETATION OF LOCAL ANOMALIES IN TERMS OF LOCAL STRUCTURE

The ability of the gravity method to outline local structures requiring no further exploration ahead of the drilling operation is possible only in limited areas. The exploration of salt domes is, of course, an example of gravity work at its best. Other areas, however, have been explored by this method to the point requiring little, if any, additional expenditures ahead of the drilling operation.

Any structure having considerable vertical relief that brings formations with pronounced density contrasts near the surface can be outlined by the gravity method. The adequacy of such exploration is determined by the depth to the interface bounding the formations of different density, the density contrast, the vertical height of the structure and its width.

The Altus structure in Jackson County of southern Oklahoma is outlined well by this method (Figs. 6-A and B). Similar structures which can be explored with equal satisfaction, are commonly found adjacent to uplifts bringing pre-Cambrian formations or massive limestones to shallow depths. The Hobbs field, in Lea County, New Mexico, which is a large structure buried at considerable depth, was discovered by gravity and magnetic exploration. No other exploration preceded the drilling of the discovery well.

It is of interest in retrospect to note how adequately gravity exploration did outline prospective fields, although other types of exploration were subsequently employed. The Stratford dome drilled by the Indian Territory Illuminating Oil Company in the Texas Panhandle, in Sherman County, Texas, provides an example. The writer is advised that this company took the original block on the basis of magnetic exploration and completed some additional work prior to drilling the first well.

An analysis of the gravity Figure 7-A and B, and magnetic data Figure 7-C, in the vicinity of this structure is of special interest. Both types of exploration

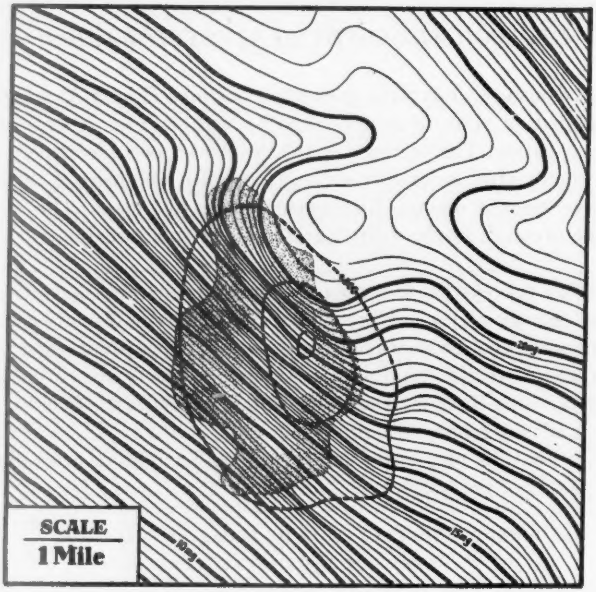

FIG. 6-A.—Gravity contours over Altus field, in Jackson County, Oklahoma. Dashed contours outline, by 100-foot intervals, structure on top of Canyon formation. Stippling encloses productive area.

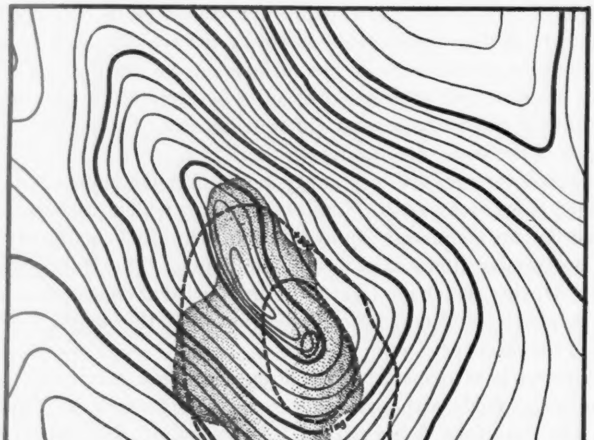

FIG. 6-B.—Residual gravity map of Altus pool shown in Figure 6-A.

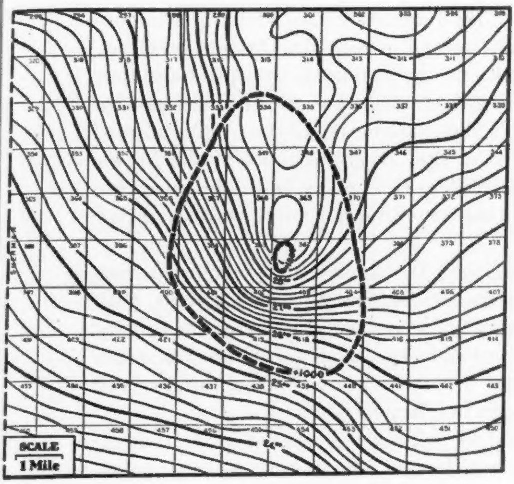

FIG. 7-A.—Gravity contours over Stafford field, in Sherman County, Texas. Dashed contour lines from structural map on top of Brown dolomite.

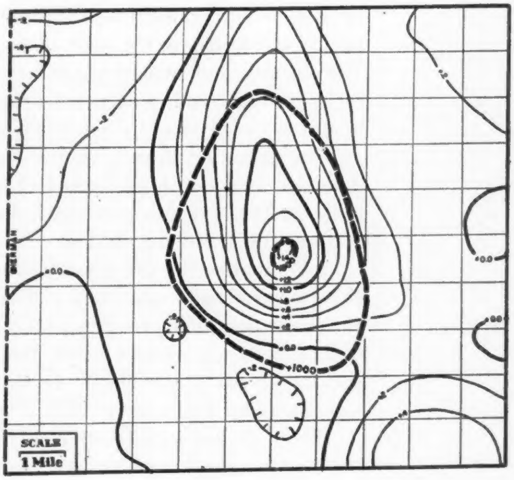

FIG. 7-B.—Residual gravity map of Stafford field shown in Figure 7-A.

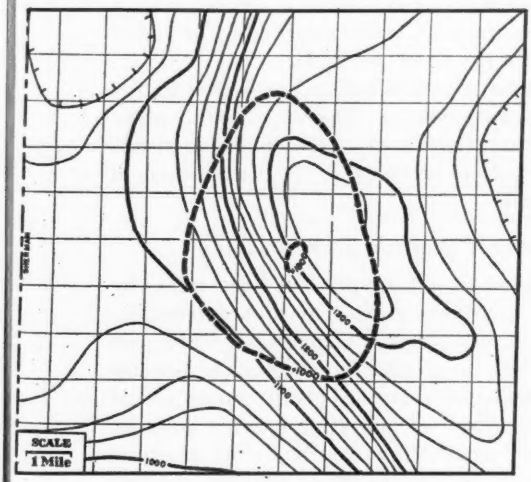

FIG. 7-C.—Magnetic contours over Stafford field shown in Figure 7-A. Contour interval, 25 gammas.

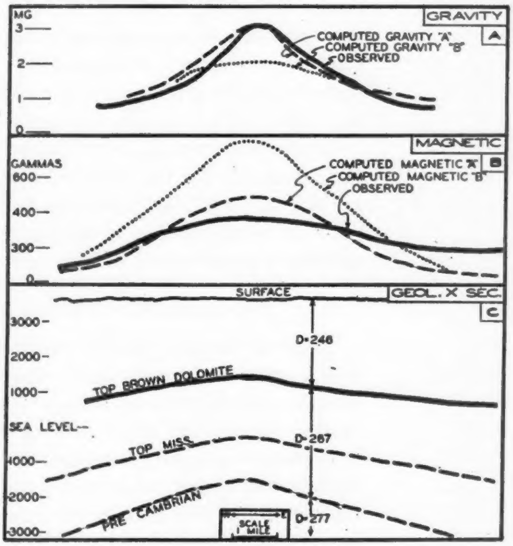

FIG. 7-D.—Geological cross section of Stafford field shown in Figure 7-A with gravity and magnetic profiles. Observed profiles (heavy lines) compare favorably with values (dashed lines) of computed gravity "A" and computed magnetic "A."

have done marvelously well in outlining the interesting area and afford opportunity to emphasize the need of understanding the geological factors involved. The density and magnetic characteristics of the sediments and pre-Cambrian rocks encountered in a deep well drilled on this structure have been determined by laboratory study and have made possible the construction of the profiles shown.

The gravity anomaly is due largely to the structural relief of the brown dolomite at a depth of 2,000 feet and its density contrast with the overlying redbeds. The magnetic anomaly is due to the structural relief of the pre-Cambrian rocks at the depth of 5,000 feet.

A comparison of the gravity profile (Fig. 7-D, Gravity "A") computed from the known density contrasts and the structures outlined by drilled wells, with the observed profile provides a satisfactory fit. Any attempt to assign the density contrasts to any surface below the brown dolomite, such as the pre-Cambrian surface, gives a profile (Fig. 7-D, Gravity "B") so far removed from the observed as to leave no doubt as to which interpretation is preferable.

Three curves have been constructed of magnetic profiles (Fig. 7-D, Magnetic): One from the observed anomaly, a second (Magnetic "A") on the assumption that the magnetic effects are confined to the pre-Cambrian rocks, and a third (Magnetic "B") computed on the assumption that the magnetic effects emanate from some formation above the pre-Cambrian in the position of the brown dolomite. A comparison of these profiles proves that the observed magnetic anomaly is due to magnetically active beds at least at the depth of the pre-Cambrian. The lack of closer coincidence of the profile of the observed anomaly with the profile representing the effect of the pre-Cambrian rocks may be due to our inability to reconstruct accurately the pre-Cambrian surface.

The evidence clearly establishes the fact that two different geological factors are responsible for the observed geophysical anomalies. The formations involved are in this particular case 3,000 feet apart. Correlative to the discussion at this point it seems possible in such a structure to predict roughly the thickness of sediments ahead of the drilling operation.

USE OF GRAVITY SURVEYS TO DIRECT ADDITIONAL EXPLORATION

Exploration by a gravity meter has low resolving power but is the means by which areas can be explored rapidly. Localizing areas of possible interest for intensive exploration by seismic or other means rightly commands a major part of the coordinated effort of this method in oil exploration. But the possible guidance of a properly processed and adequately controlled gravity survey should include much more than the simple expedient of indicating selected areas for further study. The greater value lies in the possibility of outlining the structural pattern of an unexplored area to point the way to the major features, and thus outline a long range program with emphasis on the major trends.

The analyses of a series of gravity anomalies can place them in an order of preference with intervening areas of doubtful value. A properly planned seismic

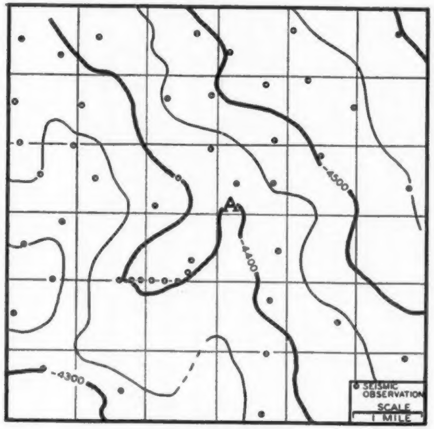

FIG. 8-A.—Contour map from seismic survey of area in Mississippi. Circles indicate points of observation. Note syncline outlined southwest of "A."

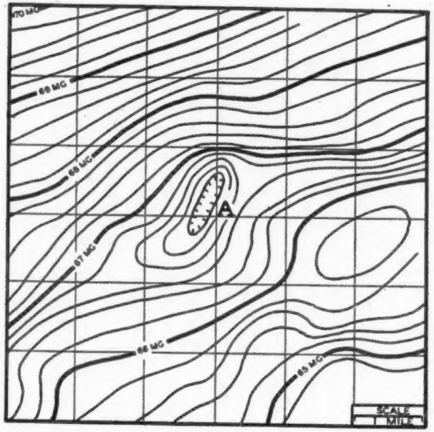

FIG. 8-B.—Gravity map of area outlined in Figure 8-A. Anomaly near point *A* is obvious and throws doubt upon adequacy of seismic map.

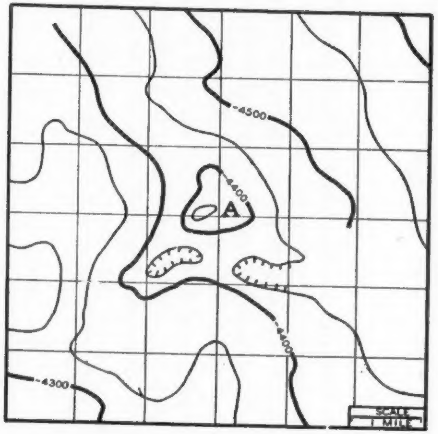

FIG. 8-C.—Final seismic map of area shown Figure 8-A after resurvey with detailed work. Although structural anomaly at *A* is small, it may be of interest in deeper strata.

exploration program which discovers the focal points of interest or the trends in a given area early in the investigation has many advantages and can complete the work with a minimum of time and expense.

Frequently an exploration method suitable for the average problem in a given province needs modification in selected areas to give proper emphasis to areas of deep-seated structural anomalies. Gravity surveys have pointed the way to many such areas where special effort has revealed features of interest not suspected by the original work. Figure 8-A is the result of a reconnaissance seismic survey which presumably adequately explored the area. A study of the gravity map (Fig. 8-B) prompted additional detailed work which provided a map (Fig. 8-C) prompted additional detailed work which provided a map (Fig. 8-B) unlike the original one.

ANALYSIS OF GRAVITY DATA AS AID TO QUESTIONABLE GEOLOGICAL INTERPRETATION

The analysis of gravity data can be used frequently to select the more probable of two alternate interpretations of geological information. Occasionally it can be used to prove that an existing interpretation of subsurface information can not prevail, even though it can not provide a solution which is unique.

With an accurate knowledge of the density characteristics of a sedimentary section, the anomaly which would be produced by any supposed structure can be computed. Frequently a comparison of such a computed anomaly with the observed gravity will make it necessary to discard the supposed structure as geologically impossible. Even if the method may not provide a unique interpretation, to prove the geological interpretation wrong or unlikely is to make a substantial contribution to the exploration effort.

The geologist is aided frequently by the application of the simplest concepts of the use of gravity maps. The geologist working in a basin known to have salt intrusions, such as the East Texas basin, is naturally inclined to assume that all wells not known to be structurally low are on some part of a salt uplift. With a "salt dome consciousness" the geologist outlines all his structures as salt domes and his map, wherever possible, is a series of circular uplifts tangent to each other. The use of a gravity map will immediately classify the "salt uplifts" into those which are probable and those which do not likely exist.

Faulting commonly provides the most prominent density contrasts to be found in gravity exploration. Obviously, the distribution of density contrasts due to thrust faulting is unlike that produced by normal faulting of equal vertical displacement. Occasionally these differences are such that a gravity survey will suggest the type of disturbance. The construction of a gravity profile assuming a normal fault may differ so much from one constructed on the basis of a thrust that a comparison of both profiles with the observed profile will suggest the nature of the faulting. An illustration of such a problem is presented later.

USE OF GRAVITY DATA IN STUDY OF REGIONAL GEOLOGY

Where the regional gravity features are not obscured by isostatic adjustments, or other extraneous effects, the gravity information can be used frequently to give important clues as to the regional geology. These regional features may be of the utmost importance in suggesting the major structural trends of the area or in bounding interesting provinces having a common geological history.

The possible extension and limits of the Appalachian environment are suggested by the "grain" of the regional gravity and magnetic features in Georgia and Florida. The possible limits of basins within which salt movement of considerable proportions has taken place are suggested by certain regional gravity maps.

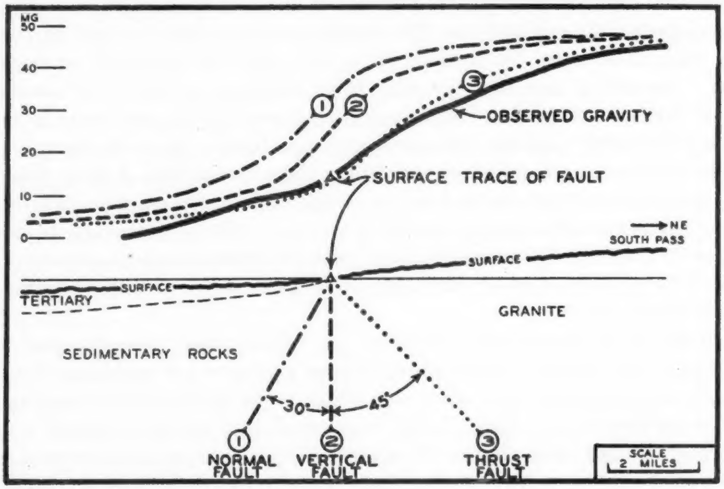

FIG. 9.—Gravity profile and cross section on southwest flank of Wind River Mountains, Sublette and Fremont counties, Wyoming. Computations of gravity are shown for (1) normal, (2) vertical, and (3) thrust faults. Comparison with observed gravity favors thrust character of faulting.

The faulted zone in southeastern Oklahoma, which is bounded on the west by the Choctaw fault, has a width of 50 miles. The regional gravity features point to the probability that this zone must be narrowed to 40 miles or less in the latitude of Dallas, and still less south of this point. Certain possible interpretations of the mechanics of this zone are suggested by the major gravity features but can not be discussed in this paper.

Regional gravity surveys on the southwest side of the Wind River Mountains, in Wyoming, provide evidence of the thrust character of these mountains. Figure 9 outlines an observed gravity profile across this mountain front. Three

computed profiles are shown using density contrasts which can be assigned to the beds involved with some confidence. One is computed on the assumption of a normal fault of 30° hade, a second on the assumption of a vertical fault, and a third on a basis of 45° angle thrust. A comparison of these profiles favors the thrust character of the faulting.

Problems on a smaller scale lend themselves to a similar analysis wherever beds of considerable thickness but of distinctly different density contrasts are brought in contact by faulting.

ADVANTAGES OF ACQUAINTING GEOLOGISTS WITH GEOPHYSICAL CONCEPTS

We have discussed for years the problem of how best to coordinate the work of the geologists and geophysicists. The following suggestions may not be new to many exploration units, but for some it may be a bit "left of center" or "right of center," depending upon the viewpoint. With emphasis on the better use of the low cost methods, the problem of geological interpretation becomes more involved and solutions other than the ones commonly considered suggest themselves.

The constant accumulation of quantities of geophysical data of many different sorts makes stupendous the problem of evaluating all of these data in terms of current problems which change rapidly. The many different procedures by which this can be done will not be a part of this analysis; however, one important phase of the problem follows which has tremendous possibilities of making better use of geophysical data.

Does it occur to you that the district or "grass roots" geologist may have many facts and alternate proposals explaining a given set of geological data besides the one he thinks most likely and which is the subject of his usual report with recommendations. Armed with geophysical data and with proper help in their use, he might find that his alternate solution satisfies both the geological facts as well as the geophysical data. Correlative to this thought is the possibility that the geophysical data would be the means of suggesting the alternate geological solution. Certainly, much is to be gained by a proper analysis of the geophysical data at the point of origin of new geological ideas.

The writer does not propose to make geophysicists of our "district" geologists, but he does contend that the geologist can be made to understand the basic geophysical concepts of the several geophysical methods and so better understand the limitations of each method and the data that each provides. Certainly, the possibilities of unpredicted velocity changes in the weathered layer and changes in its thickness are no more difficult to comprehend than the use of the electrical and gamm-ray logs which the geologist continually interprets. He can as readily learn to appreciate the fact that an unconformity may bring beds of unlike density in contact in sufficient quantity to become a problem for gravity exploration as he has learned to correlated insoluble residues. Faced with the necessity of assisting in the interpretation of geophysical data the geologist on the ground is in a posi-

tion to see that the best possible geological facts are forthcoming by which to process these data.

Too frequently we as geologists have dumped our geological problems into the laps of the geophysical departments and have become inert in regard to any new geological thinking. Too often we have become scouts simply reporting geological data or bookkeepers and clerks in a highly complex oil-finding organization. To what group, or individual, do we look for new ideas in our day to day problems? If we look to the geologist on the ground, the one nearest the source of geological data, he should be a member of the group which makes the final assembly of the total information. It is obvious that the geologist responsible for the current recommendations should be able to grasp geophysical concepts.

An increase in the number of geologists in the Society of Exploration Geophysicists marks a trend, however small, in the right direction. In 1940 approximately 7 per cent of our members had qualified and were on the roles of the S.E.G. In 1945 almost 9 per cent held membership in both societies. Inasmuch as the predominate expense of the oil-finding effort with which the geologist is concerned is so overwhelmingly geophysical, and will remain so in the foreseeable future, it should concern all of us to see that these percentages reach higher levels.

The most important reason the geologist, and especially the district geologist, should become acquainted with geophysical data to the point where he can use them under guidance is that such data can be the means of stimulating his imagination toward the birth of new ideas.

The optimum in geological-geophysical interpretation will be reached when one individual, or group of individuals, acts as a focus for all the geophysical data and geological information for final analyses. Obviously, the geologist on the ground who presumably is most familiar with the problems must be one of this group, and insofar as it is possible for members of this group to grasp the significance of any or all of the geophysical and geological data, in just this measure will the fullest possible use be made of the information.

Give the geologist to whom you look for new ideas freer access to geophysical information and instruct him in its interpretation. Such a scheme will stimulate his imagination and at the same time have it under control, thus providing the controlled imagination needed in our geological thinking.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 12 (DECEMBER, 1946), P. 2034.

GEOLOGICAL NOTES

ELMORE EMBAYMENT, GARVIN COUNTY, OKLAHOMA[1]

ROBERT R. WHEELER[2]
Oklahoma City, Oklahoma

During the last year the discovery of several new Pennsylvanian (Deese) sand pools spotted in an arc around the basinward flank of the Pauls Valley uplift, chiefly in Garvin County, Oklahoma, makes it desirable to coin a term of differentiate the contiguous southeastern extension of the Anadarko basin. For this depressed area between the Pauls Valley and Arbuckle uplifts, the term Elmore embayment is proposed.

Structurally, the embayment developed as a complex graben comprising a series of northwest-trending fault blocks successively down-dropped southwest of the Pauls Valley uplift and northeast of the Robberson-Arbuckle uplift. Differential truncation in pre-Deese time left Caney and early Pennsylvanian rocks in the depressed area, but removed successively older rocks on the bordering positive areas.

The succeeding Deese and younger Pennsylvanian deposits lapped out on the Pauls Valley uplift and doubtless thinned over the Arbuckle high where later erosion unfortunately penetrated the Deese and older sequence to remove generally the essential evidence.

The town of Elmore, in Sec. 27, T. 2 N., R. 2 W., Garvin County, Oklahoma, is situated near the axis of the embayment which is apparently traceable southeastward into the well known Mill Creek syncline of the Arbuckle Mountains.

[1] Manuscript received, October 16, 1946.

[2] Chief geologist, Eason Oil Company.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 12 (DECEMBER, 1946), PP. 2035-2041, 3 CHARTS.

DISCUSSION

STATISTICS OF EXPLORATORY DRILLING[1]

W. J. DIXON[2] AND R. M. SWESNIK[3]
Eugene, Oregon, and Oklahoma City, Oklahoma

The development of many branches of science proceeds along somewhat similar lines. It is possible that the technological science of exploratory drilling will develop in a similar manner to other sciences. The preliminary stage of exploration which is one of reporting observations upon special cases and methods, is followed by the collection of groups of data obtained in various lines of investigation. Thereupon, attempts are usually made to lay down general rules which the data may indicate and to attempt generalizations. It becomes necessary at this stage to define more precisely and concretely the vocabulary used in obtaining more nearly uniform data. As these definitions become generally accepted, the assembled data become more consistent so that summaries of data take on definite meaning. Also, when the data acquire a generally accepted meaning, they may be used more widely and they begin to have application in charting the development of the science.

At such time it becomes advantageous to apply various techniques in descriptive statistics such as graphs, charts, ratios, percentages, and mathematical approximations to the observed data. For as the data gathered become extensive, it is necessary to use methods of organization to bring the facts within the compass of our understanding, methods of analysis to make the essential relations appear out of the mass of detail in which they are hidden, and methods of classification and description to facilitate the presentation of the data for the study and consideration of other persons. When the data are organized in this manner it becomes possible to make predictions for the future, for, in order to plot the future development in a science, it is necessary to make a careful study of the rate and direction of the development in the past. Further, such investigations often propose new questions to be answered.

These various processes are collectively known as the statistical method. Some of these processes are simple and others elaborate, involving complicated mathematical methods and conceptions. The development and application of these methods constitute a distinct science. The simple processes have a wide general use while the more elaborate processes have specific applications in special cases.

The petroleum industry appears to be passing through these same phases. It now has a well defined vocabulary with respect to exploratory drilling. This was greatly facilitated in 1944 by F. H. Lahee,[4] who has taken an active interest in compiling data on exploratory drilling,[5] and was necessarily led to a standardization and formulation of precise definitions.

[1] Manuscript received, October 24, 1946.

[2] Professor of mathematics, University of Oregon.

[3] Geologist, Anderson-Prichard Oil Corporation.

[4] Frederic H. Lahee, "Classification of Exploratory Drilling and Statistics for 1943, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 6 (June, 1944), pp. 701–21.

[5] *Idem*, "Wildcat Drilling in 1935 and 1936," *ibid.*, Vol. 21, No. 8 (August, 1937), pp. 1079–82.
———, "Wildcat Drilling in 1937," *ibid.*, Vol. 22, No. 6 (June, 1938), pp. 645–48.
———, "Further Data on Wildcat Drilling in 1937," *ibid.*, Vol. 22, No. 9 (September, 1938), pp. 1231–35.
———, "Wildcat Drilling in 1938," *ibid.*, Vol. 23, No. 6 (June, 1939), pp. 789–99.
———, "Wildcat Drilling in 1939," *ibid.*, Vol. 24, No. 6 (June, 1940), pp. 953–58.
———, "Wildcat Drilling in 1940," *ibid.*, Vol. 25, No. 6 (June, 1941), pp. 997–1003.

As an example of the application of descriptive statistics to such data, a few graphs and computations are presented, based on Lahee's compilation of data in the June, 1946, issue of this *Bulletin*.[6] No attempt is made to make a complete analysis of the type possible

CHART I

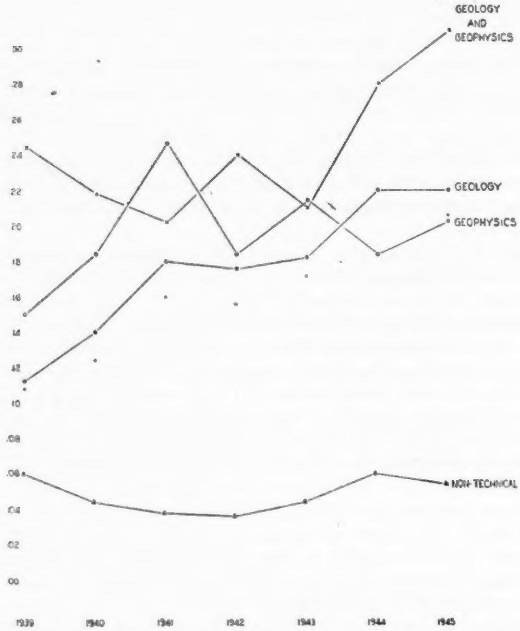

CHART I

at this time. Also, many very interesting statistical studies await the time when data have been accumulated for a greater number of years.

Lahee[7] expressed much more confidence in data for the years following 1938; there-

———, "Wildcat Drilling in 1941, with Comments on Discovery Rate," *ibid.*, Vol. 26, No. 6 (June, 1942), pp. 969–82.

———, "Wildcat Drilling in 1942," *ibid.*, Vol. 27, No. 6 (June, 1943), pp. 715–20.

———, "Classification of Exploratory Drilling and Statistics for 1943," *ibid.*, Vol. 28, No. 6 (June, 1944), pp. 701–21.

———, "Exploratory Drilling in 1944," *ibid.*, Vol. 29, No. 6 (June, 1945), pp. 629–45.

———, "Review of Exploratory Drilling Statistics, 1938–1944," *ibid.*, Vol. 29, No. 11 (November, 1945), pp. 1581–92.

[6] ———, "Exploratory Drilling in 1945," *ibid.*, Vol. 30, No. 6 (June, 1946), pp. 813–28.

[7] *Ibid.*

fore, data from earlier years are not considered here. The years 1939 to 1945 give us, statistically speaking, a sample size of seven (based on years), which is actually very small for a time-series analysis; therefore, any predictions made are not as precise as they would be with a larger sample size. Nevertheless, several interesting inferences are possible.

In addition to the presentation of the data given by Lahee, mainly in tabular form, a presentation of part of the data in graphical form should serve to show more clearly some of the fundamental trends. Also, one may more readily determine the basic fundamental mathematical laws these curves follow. Of course, the graphical presentation has the disadvantage of requiring more space, but if such data are of interest, the extra space required may be worthwhile.

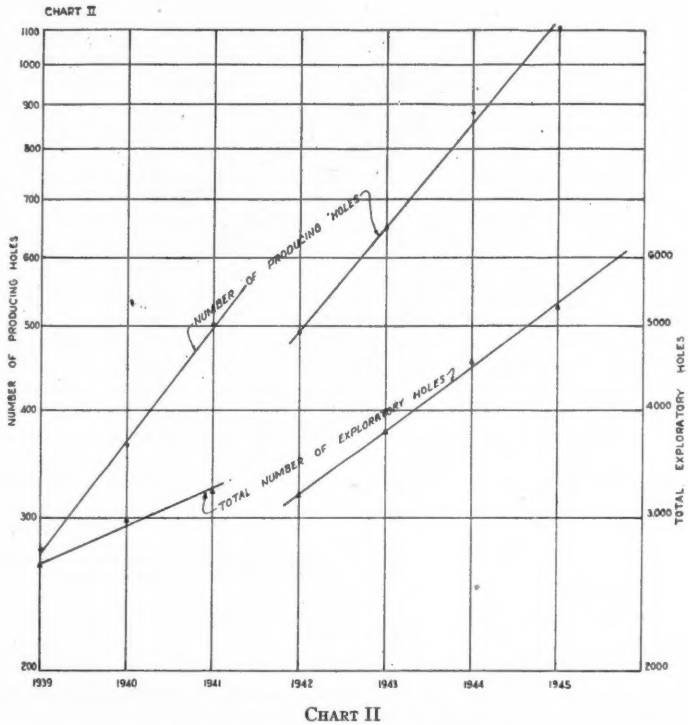

CHART II

Of primary interest to all petroleum geologists are these questions: (1) How effective are our methods? (2) How do our methods compare with those of the geophysicists and can we be of aid to them? Further, (3) how much more effective are our methods than sundry non-technical methods? To answer these questions let us critically examine Chart I. This chart was prepared from Table VII, page 825 of Lahee's article.[8] The points plotted were obtained from his data by finding the ratio of producers and dividing this to the

[8] *Ibid.*

total number of producers and dry holes in each category for every year. If this quotient be defined performance, we can then compare methods in terms of performance.

First, let us examine the performance of the geologists. It is readily seen that since 1939 they have steadily improved each year with the exception of 1941 to 1943, when their performance remained essentially constant. Perhaps this may be attributed to the addi-

CHART III

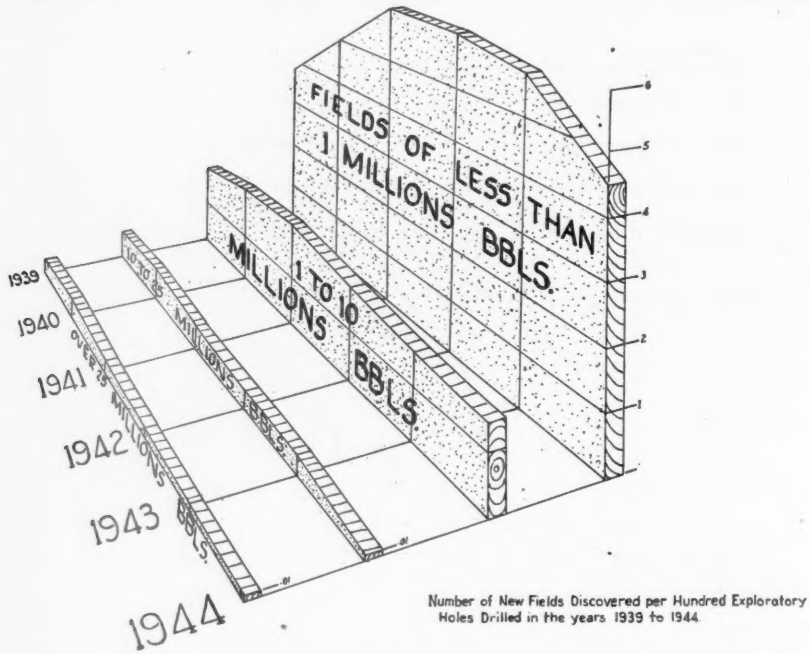

CHART III

tional load they were obliged to carry due to the war, with the resultant lack of research. However, after the stabilization period they again improved.

The geophysicists have had a rather fluctuating performance, dropping off to a performance record of 0.18 in 1944. This fluctuation again shows the results of the war. For the years 1939 to 1943, the geologists were between 0.04 and 0.06 unit behind the geophysicists. From a comparison of the two methods, it seems as though the geophysicists' performance is erratic from year to year and is not improving, whereas the geologists' performance is steadily improving and is now superior to the purely geophysical methods.

Working together the geologists and geophysicists have consistently had an appreciable edge on any other method. Only in 1941 was their combined performance less than by any other methods. In 1944 and 1945 their high performance may be due to better geologic technique, for in those years the geologists alone showed a much better performance than the geophysicists.

Sundry non-technical[9] methods have had less and less success until 1944, when their performance increased to 0.08, the highest for the period 1938–1945. A likely explanation might be that what has been considered non-technical in 1944 might have been considered technical 7 or 8 years previous, due to the rapid advances made in the technique of exploratory methods. However, their performance did not further increase in 1945.

The total of all these methods indicated by unjoined dots, shows steady improvement. It may be predicted by extrapolation of this trend that the total performance for 1946 of all methods will be approximately 0.23.

Chart II shows the number of producers and total number of exploratory holes drilled for the several years considered. It appears that the outbreak of war affected the number of wells drilled and held this number essentially constant for 12–14 months. The points have been plotted with the coordinates adjusted (semi-logarithmic coordinates) so that exponential curves will appear as straight lines. The fact that these points lie in essentially a straight line here indicates that the numbers are increasing exponentially. There appears to be an essential difference in the drilling operations before 1941 and after 1942. Exponential curves fitted to the data from 1942 to 1945, inclusive of the general form $N = A \cdot B^t$ where t represents time. 1942 is $t = -4$, 1943 is $t = -3$, 1944 is $t = -2$, 1945 is $t = -1$, and 1946 is $t = 0$. For producers the curve is 1,480 $(1.32)^t$; for total number of holes is 6,320 $(1.20)^t$. The ratio of these two quantities for 1946, which we have defined as performance, gives 0.234. The ratio of the two quantities is 0.5 for 1952. It is of interest that a performance of 0.5 is predicted for 1952. This means that half of all exploratory wells will be successful in 1951 if present trends are followed. This may be attributed to several possible causes, the most plausible being that now with the mass of subsurface data both geophysical and geological work is improving, and also the fact that more wells are being drilled on geological and geophysical data and less on sundry non-technical methods. Any basic change in methods which alters the trend or further information on the type of curves to be fitted to the data may, of course, alter the picture. It must be borne in mind, however, while performance in 1952 may be 0.5, that the size of fields is apt to be much smaller as indicated by the present trends.

Chart III shows the number of new fields discovered per 100 exploratory holes drilled. The data are divided into groups according to the probable size of the field. In general, the picture indicates that over a period of years the average size of field being discovered is decreasing. In the last 4 years, however, the number of fields of more than 10 million barrels productive capacity per 100 exploratory holes has continued to decrease and there has been no increase, in fact, a slight decrease, in the number of the smaller fields discovered per 100 exploratory holes. The number of fields of less than 1 million barrels has dropped sharply in 1944.

It is pointed out, in conclusion, that with the ever accumulating data on the success of various exploration techniques, conclusions of great economic significance not previously obtainable can be drawn by the application of proper statistical methods.

[9] Sundry non-technical methods as considered by Lahee are "creekology," "hunch," "doodlebug," promotion, lease obligation, reported showing of oil or gas in holes previously drilled, *et cetera*. Vol. 28, No. 6 (June, 1944), p. 713.

TECTONIC FRAMEWORK OF NORTHWESTERN SOUTH AMERICA[1]

F. E. von ESTORFF[2]
New York, N. Y.

In his discussion of the writer's recent paper "Tectonic Framework of Northwestern South America"[3] Victor Oppenheim[4] has offered some criticism which indicates the need for clarification of the points raised.

The writer fully agrees with Victor Oppenheim that "the forces that acted upon and shaped this part of South America are manifold and complex." However, as pointed out by the writer in his introduction the purpose of the paper under discussion was "to analyze the rigid framework of the basement complex." In order to accomplish this an attempt was made to eliminate the confusing effect of minor structural elements so as to distinguish the major and persistent elements of the framework. Many and varying less persistent trends locally seem to be very significant. On studying regional structural relations, however, it can be observed that the less persistent trends are most common at the junction of the major northeast and northwest trends and appear to be the result of the composite effect of the two major elements. This applies for instance to eastern Venezuela and may also apply to Santa Marta.

As to a north-south structural trend of the Andean Ranges between 18° and 50° Lat. S., both physiography and structure suggest that alternating northeast and northwest elements are responsible for the apparent north-south trend. The two elements are even more definitely expressed in the structural pattern of adjacent Argentina.

The division of areas into "positive" and "negative" is based not "on present topographic forms related to an arbitrary 6,500-foot level" but on areal geology reflecting structure. The areas above 6,500 feet were merely added to show the relation between high mountains and outcrops of basement or igneous rocks which offer the principal evidence of the rigid framework. The old positive areas actually reflect barriers between sedimentary basins whereas the younger positive areas indicate more recent uplift across former basins of deposition. For detailed geologic evidence of trends the reader is referred to the "Geologic Map of South America"[5] and the "Source of Geologic Data" listed on this map.

The difficulty of separating relatively young volcanics from pre-Paleozoic igneous rocks has been fully appreciated by the writer as stated on page 583:[6] "Although it would be preferable to separate the younger igneous intrusives from the area of rigid rocks representing the older framework not all can be separated due to our present limited knowledge." However, the orientation of these younger igneous rocks along the same major trends strengthens rather than weakens the theory as set forth in the paper under discussion.

Evidence of structural trends other than northeast-southwest in southern Brazil and Uruguay does not necessarily contradict the physiographic evidence of a major northeast trend along the coast, a trend which is confirmed and even better expressed in the form lines of the continental shelf and slope.[7] The shelf contours off the coast of Brazil inci-

[1] Manuscript received, October 19, 1946.

[2] Socony-Vacuum Oil Company.

[3] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 4 (April, 1946), pp. 581–90.

[4] *Ibid.*, Vol. 30, No. 9 (September, 1946), pp. 1589–90.

[5] *Geologic Map of South America.* Published by the Geological Society of America (1945). Scale, 1:5,000,000.

[6] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 4 (April, 1946), p. 583.

[7] *Geologic Map of South America.*

dentally offer the most prominent physiographic evidence of a northwest cross-trend between Lat. 21° S. and Long. 33°–40° W. Physiographic or geologic evidence of a dominant northeast or northwest element naturally does not exclude the possibility that there were older trends which are less discernible to-day and on which the northeast and northwest trends have been superimposed.

The writer wishes to express his appreciation for the interest in this problem by Victor Oppenheim whose geologic work in South America has greatly added to our knowledge of the geology of this continent. It is hoped that the present discussion will clarify the points in question and contribute to a better understanding of regional tectonics.

DISTINGUISHED LECTURE TOUR

H. N. Fisk, professor of geology at Louisiana State University, Baton Rouge, Louisiana, spoke before the following groups in December. His subject was "Geology of the Lower Mississippi Valley." Fisk's duties as a consultant for the Mississippi River Commission and his extensive studies of the geology of the Gulf Coast make him one of the foremost authorities on the Lower Mississippi Valley area. He points out, geologically speaking, that the Mississippi River is one of the youngest major streams in the world inasmuch as it had its origin in early glacial time.

December 2—Mississippi Geological Society, Jackson
3—Southeastern Geological Society, Tallahassee, Florida
5—Indiana-Kentucky Geological Society, Evansville, Indiana
6—Geological Club, University of Wisconsin, Madison
9—University of Iowa, Iowa City
10—Illinois Geological Survey, Urbana
12—Tulsa Geological Society, Tulsa, Oklahoma
13—Shawnee Geological Society, Shawnee, Oklahoma
16—North Texas Geological Society, Wichita Falls
17—East Texas Geological Society, Tyler
18—Houston Geological Society, Houston, Texas
19—South Texas Section, A.A.P.G., San Antonio
20—Corpus Christi Geological Society, Corpus Christi, Texas
23—South Louisiana Geological Society, Lafayette

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VOL. 30, NO. 12 (DECEMBER, 1946), PP. 2042-2063

RESEARCH

FINAL REPORTS ON A RECONNAISSANCE SURVEY OF RESEARCH NEEDS IN PETROLEUM GEOLOGY

BY

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS RESEARCH COMMITTEE

1945–1946

FOREWORD

The Research Committee of 1945–1946 completed a reconnaissance survey of research needs in petroleum geology and recommended nine major projects as needing formulation. These projects have been approved by the Executive Committee and have been assigned to project chairmen. It is expected that formulation of all nine will be completed this year.

There was no thought of making a complete survey but only of completing a reconnaissance. It is not surprising, therefore, that two additional projects have already been added to the list. Still others will probably be developed during the formulation of the ones already adopted, and it seems reasonable to suggest that this initial group may gather momentum, under the impetus of interest and urgency.

The following report by Philip B. King, chairman of the Subcommittee on Tectonics, is the first of three that will be published in the Research Department in the *Bulletin*. The other two, giving the results of the survey on Stratigraphy and Sedimentation, and Reservoir Fluids, will appear early in 1947.

These reports speak for themselves. It is a pleasure and a privilege, once again, to thank their authors and the other members and consultants of the Research Committee who aided in this work.

SHEPARD W. LOWMAN

REPORT OF SUB-COMMITTEE ON TECTONICS[1]

PHILIP B. KING,[2] CHAIRMAN
Washington, D. C.

TABLE OF CONTENTS

[1] Published by permission of the director, Geological Survey, United States Department of the Interior.

[2] United States Geological Survey.

INTRODUCTION

This report summarizes the status of research in tectonics, and especially of research which relates to petroleum exploration. It also summarizes the work and the recommendations of the sub-committee on tectonics of the research committee of the American Association of Petroleum Geologists between September, 1945, and April, 1946.

SCOPE OF SUBJECT

What is tectonics? The word is derived from the same root as "architecture" and may be thought of as "the architecture of the earth." Webster's dictionary defines it as "that branch of geology concerned with rock structures, especially folding and faulting, resulting from deformation of the earth's crust." As such, the term is more or less synonymous with "structural geology" as this is used in geologic reports, text books, and college courses.

The field of tectonics is broad and rather indefinite, with many overlaps into other branches of the earth sciences. A worker in tectonics must consider not only the rock structure itself, but also stratigraphy, geologic history, geomorphology, and geophysics. Conversely, much work done in stratigraphy, historical geology, geomorphology, and geophysics has tectonic implications. Much work in tectonics is done along with or as a by-product of other work. Every geologist who prepares a geologic map or well-log cross section must consider geologic structure, but the amount and significance of the structure are variable.

The present report is limited to that part of tectonics which relates to petroleum geology and petroleum exploration. Considered narrowly, this would limit the scope of the report to only part of the field, as petroleum is not likely to be found in igneous and metamorphic rocks except at or near their contact with the sedimentaries. In fact, the projects discussed which have most immediate practical value are restricted in subject matter. Nevertheless, petroleum geology overlaps into so many diverse fields that effective long-term progress would seem to be best served by taking a broader view, even though the apparent relation of some of the subject matter to petroleum geology may seem remote.

RESEARCH IN TECTONICS

Research in tectonics may be grouped into three categories: (a) fact gathering, (b) assemblage and synthesis of facts, and (c) research leading to an interpretation of facts. The relative merits of the three types have been much debated. The extreme view has been expressed that the first two categories are not research at all, or at least not "fundamental" research of the sort that should interest us. Also, that work of this sort would merely duplicate that done by oil companies as a part of their routine commercial operations. A similarly extreme view has been expressed that the third type is too far removed from the present needs of petroleum exploration to be of practical value. Probably neither of these extremes is justified.

In this connection, two more moderate expressions of opinion deserve quotation. Reed and Hollister,[3] in their discussion of the tectonics of southern California, point out the dangers of making purely speculative explanations of the mechanics of structural features, when the features themselves and their geologic history are poorly known or poorly synthesized

> Structural geologists . . . will wonder . . . where the writers propose to discuss the dynamic problems that bulk so large in most treatises similar to the present one. What is the nature of the forces that from time to time have deformed the crust of coastal California, and what is their origin? Were the mountains warped up, thrust up, or elevated in some other way? To all such questions the writers must answer that they do not know. They must state further that in spite of their best efforts they do not yet know as definitely as they would like just what structural events happened from time to time and from place to place in the California province; and they may as well confess that they doubt the advisability of creating mechanical hypotheses, except for mnemonic purposes, until the succession of events to be explained has been well worked out.

M. K. Hubbert points out the need for actual research (as opposed to speculation and deduction) on the origin of structural features, making use of mechanical and other principles that have been developed in the physical sciences:

> For many years geologists have been making and recording very good observations on geologic structures. They have also frequently sought to give some kind of a mechanical explanation of the manner in which these structures have originated. Unfortunately these attempts have most often been very naive and quite inadequate for the fulfillment of the purpose for which they have been intended. My feeling is that an empirical knowledge of any subject, although perhaps necessary as a first step, can hardly be said to be more than half the required development of that subject. In structural geology, our knowledge has barely gone beyond this empirical stage. Consequently, to my way of thinking, the most important research that remains to be done in the field of tectonics is to bring our understanding of the physics of such phenomena to where it is comparable to our empirical knowledge of the subject. This is partly a problem in complex mechanics—the mechanics of deformable bodies—partly a problem of gravitational potential, and partly a problem in thermodynamics.

WORK OF THE SUB-COMMITTEE[4]

The sub-committee on tectonics of the research committee of the Association was organized in September, 1945, and served through April, 1946. It included the following members of the main research committee: A. H. Bell, P. B. King, R. A. Liddle, and W. T. Thom, Jr., with King as chairman of the sub-committee. In addition, the following other geologists acted as consultants: W. H. Bucher, Ernst Cloos, James Gilluly, M. K. Hubbert, C. R. Longwell, and C. W. Tomlinson.

From September to January a survey was made of the field of tectonics and its research possibilities. A preliminary outline of the subject matter was prepared and circulated, and

[3] R. D. Reed and J. S. Hollister, "Structural Evolution of Southern California," *Bull. Assoc. Petrol. Geol.*, Vol. 20 (1936), p. 1685.

[4] For a general summary of the work of the research committee, see S. W. Lowman, chairman, "Report of the Research Committee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 787–89.

written comments and contributions were solicited from committee members, consultants, and geologists in general. A meeting of the sub-committee was held toward the end of December at the Pittsburgh convention of the Geological Society of America, at which many issues were clarified.

The fruits of this work were embodied in a preliminary report of the sub-committee that was submitted in mid-January. This was issued as a chapter in the general progress report of the research committee.[5]

A second meeting of the sub-committee on tectonics was held in early April at the Chicago convention of the American Association of Petroleum Geologists. Here, the main objective was to summarize the survey that had a ready been made, and to crystallize the results into concrete recommendations. These are given under the next heading.

The present report includes the survey of tectonics and the recommendations resulting from it. It was written by the chairman (P. B. King) who has edited and coordinated the contributions of the other geologists, summarized the results of discussions at meetings of the sub-committee, and added appropriate published material. The report contains much of the material presented in the earlier preliminary report, but with some additions and deletions.

RECOMMENDATIONS

In reviewing the subjects and projects listed in its preliminary report, the sub-committee found that they could appropriately be grouped into four classes:

1. *Recommended.*—Projects favored by the sub-committee and deserving the support of the Association, in order that they may be either initiated or completed.

2. *Commended.*—Projects favored by the sub-committee, but already being successfully carried out by other research groups.

3. *Formulation needed.*—Projects favored by the sub-committee, but on which information is lacking as to details of objectives, personnel, funds required, etc. If detailed formulation can be made, the sub-committee would wish to reclassify them as recommended projects at a future time.

4. *No action.*—Subjects or projects that are either indefinite in scope, out of the main line of interest of petroleum geology, or of more direct concern to another sub-committee (stratigraphy, geophysics, *et cetera.*) None of these projects is disapproved, and some might materialize into recommended projects at a future time.

In this classification, relatively few projects can be placed in the first, or immediate class at the present time, and most of these are along the lines of fact-gathering and synthesis, rather than the more fundamental interpretative research. This is perhaps a natural result of the particular time at which the report is written. Possibly as post-war conditions become stabilized more detailed formulation of interpretative projects will become possible.

The sub-committee's grouping of subjects and projects in the first three categories is as follows. Numbers serve as cross-reference to descriptions in the text that follows.

1. *Recommended*
   a. Areal geology of United States, on 1:62,500 or similar scales (1)
   b. Geologic maps of states, on 1:500,000 or similar scales (5)
   c. Revision of tectonic map of United States (11)
2. *Commended*
   a. Work of Fuels Section of United States Geological Survey (8)
   b. Work of Yellowstone-Bighorn Research Association (9)
   c. Geologic structure maps of states (6)
   d. Contour map of United States on top of basement rocks (13)

[5] S. W. Lowman, chairman, *Progress Reports of the Research Committee* (mimeographed book), Amer. Assoc. Petrol. Geol. (January 15, 1946).

3. *Formulation needed*
   a. Detailed study of salt domes (3)
   b. Studies of fracture systems (10)
   c. Laboratory experiments (20)

LOCAL PROJECTS

Under the heading of local projects are grouped those which deal with small areas, such as oil fields and groups of oil fields, quadrangles, and significant minor structural units. Most of the proposals represent basic fact-gathering, the first type of research listed above, to be carried out by the conventional methods of field mapping and detailed subsurface study. The immediate effects of such work are small and practical; the development of individual oil fields or extension of fields, or the analysis of some structural feature of second or third order.

However, work of this sort already constitutes much of the day to day routine of the oil companies, so that any projects suggested should have larger or more philosophical implications. Areal mapping is thus not considered significant unless the blocks of quadrangles are large enough to contribute to a regional picture. Studies of oil fields and local structural features are not proposed unless they contribute to a regional problem or are representative of a general structural type.

1. *Areal geology of United States.*—The sub-committee on tectonics recommends the completion of the geologic mapping of the United States on a large scale (1:62,500, 1 inch to the mile, or some comparable scale) and its publication in a uniform, readily accessible series of sheets.

This project is not strictly tectonic, but falls more in the class of general geology. However, it will serve as the fundamental basis for a large amount of research in geology, be it in tectonics, stratigraphy, geophysics, or petroleum geology. Blocks of contiguous quadrangles would illustrate the character of individual regions, and the maps could be used as a starting point for technical and specialized investigations.

Recommendations of petroleum geologists as to areas that should be given priority would perhaps be desirable—such areas being those that would aid in oil finding, or aid tectonic and other research of interest to petroleum geologists. However, A. I. Levorsen expresses the opinion that petroleum geologists would be interested in the mapping of any areas of sedimentary rocks.

Relatively minor considerations, but of interest to petroleum geologists, are the facts that oil fields continue to be discovered for which there are good surface indications, and that such an extensive program might furnish training in field work for prospective petroleum geologists, a training whose need has been stressed by F. H. Lahee.

Considerably less than half the country is now adequately mapped by modern standards, and many geologic notions that we consider well established actually rest on an insecure basis of inadequate mapping. Existing mapping is, moreover, difficult to locate, because it appears piecemeal in a host of publications: federal and state bulletins, society organs, technical journals, or even in guidebooks or other ephemeral publications. The maps generally cover irregular areas, some overlapping on others, some failing to meet or match; they are on all conceivable scales, and vary widely in form of presentation, symbols used, *et cetera.*

A start at a uniform series of large-scale geologic maps was made by the United States Geological Survey in its folio series, following out the authorization of the Survey to prepare a geologic map of the United States. This series has been virtually abandoned for many years, although the present administration of the Survey is considering reviving it in modified form. Many of the older folios are now obsolete and would require redoing to bring them up to modern standards of representation, interpretation, and scale. Nevertheless, the plan behind the old folio series deserves reconsideration now—uniform set of

sheets in quadrangle form, constituting a single and thus readily accessible series.

Areal geologic mapping of this type could probably best be carried out by the United States Geological Survey, but with the cooperation of the State Surveys. Possibly university work (faculty research and thesis problems) could in some manner be integrated with the program. Oil companies at present do comparatively little surface mapping, and then only of selected areas of immediate interest. The work would therefore not duplicate oil company work and yet would furnish valuable background material for petroleum exploration.

In connection with the confusing status of existing mapping, attention should be called to a catalogue of all areal geologic maps in the United States which is now nearing completion, the work being done under the direction of Miss Leona Boardman for the United States Geological Survey. Areas covered by published maps are outlined on a set of state maps, and cross-referenced by number to a bibliography. Plans for publication have not yet been made, but such publication would seem to be of great aid to geologists of the United States.

2. *Structure symbols on maps.*—In connection with the preparation and publication of areal geologic maps, it is of interest to consider Ernst Cloos' plea for more adequate use of structure symbols on maps:

> I would like to see this committee take a strong stand . . . on the use of structure symbols on geologic maps. Some time ago I sent a report to the Geological Society of America that structure symbols are lacking in 25% of all the U. S. Geological Survey maps, where the Alaskan Branch is the worst offender, and that even the Geological Society does not force the author to put them on. . . . I think the time has come that structure symbols be put on maps as they have done in England, Scotland, Sweden, Norway, etc. since 1868. . . . I think that this tectonic committee should push that point vigorously, and perhaps . . . the Geological Survey would progress another little step and with it all the State Surveys too.

There is some question as to how far the geologist should go in observing and recording structural observations, especially in the course of an ordinary areal survey. Some features have only specialized value and could best be studied during tectonic research that would follow the general mapping of the area. However, every good field man observes and records certain features during the course of his work and perhaps these could be set up as minimum standards for an areal geologic map: dips and strikes of bedding, overturning of beds (where present), dips and strikes of cleavage, upthrown sides of faults, dips of faults (where observed), anticlinal and synclinal axes, and pitch of axes. Even these data may crowd the map unduly, and in this case might be shown on a separate map or oversheet, along with additional features such as lineation, flow lines, distribution of fractures, and structure contours, for which the author of the map might have obtained data.

These remarks apply particularly to regions of considerable deformation. Many such regions are outside the field of interest of petroleum geologists, but they are not lacking in oil-bearing regions. Many petroleum geologists with whom the writer has discussed the matter have expressed the opinion that representation of structure in oil-bearing regions is adequate, and point to the oil and gas maps of the Fuels Section of the Geological Survey as setting a desirable standard. In such areas, most of the structure can be represented adequately by structure contour lines, but there might perhaps be need for further attention to dips of faults, distribution of fractures, and other features that sometimes escape notice.

3. *Detailed study of salt domes.*—M. K. Hubbert outlines a program for a detailed study of salt domes. The most important part of the work would be a structural study of exposures in mine workings in the domes, there being such workings in five or six of them. These exposures show flow structure and other features of the salt core that would be capable of observation and analysis after the fashion of similar observations that have been made on igneous intrusions. This information could then be fitted into its proper setting in the dome as a whole by use of oil company drill records and other data. Hubbert states

that Professor Robert Balk is interested in undertaking such a project. It would require a grant of research funds and the cooperation of various mining and oil companies.

In connection with detailed study of salt domes, Hubbert calls attention to a paper by O. Wilhelm presented at the 1945 meeting of the American Geophysical Union, and now nearly ready for publication. He states that this represents one of the most detailed studies of the faulting associated with salt dome structure made so far, and is based almost entirely on the results of drilling.

4. *Detailed studies of other oil-bearing structures.*—Hubbert's proposal suggests to the writer that other types of oil-bearing structures (anticlines, domes, fault blocks, *et cetera*) might repay similar structural analysis, with a view of adding to our knowledge of the mechanics of their formation. As underground workings are not present on most of them, such studies would consist largely of observations at the surface of fracture systems, faults, minor folds, *et cetera*. Possibly features known to be representative of a general type and characterized by exceptionally good exposures could be selected. An example of such work is that done in the Kettleman Hills by the United States Geological Survey.[6] This subject overlaps on that of a proposed study of the regional distribution of fracture systems that is discussed under a later heading (10).

In this connection, Robert Balk suggests:

> . . . that we organize somewhere a clearinghouse of information on *unusually well exposed areas*. Being essentially a free-lance in my field work, my constant worry when starting a new problem is: if only exposures will be good! I suspect that in the aggregate our fraternity wastes much time (as far as structural questions are under investigation) in poorly exposed areas. This is particularly true in fracture studies. For work on joints, exposures cannot be too good. If we had some very good monographs on exceptionally exposed areas, I think they would be of much general value, regardless of where the region in question may be.

S. W. Lowman points out that a new volume on the structure of typical oil fields is being planned by the Association and that a study of volumes previously published would be desirable with a view of determining what new subjects need to be treated, wherein the older papers need revision, and how classification of oil-bearing structures can be improved. Wilhelm's[7] recent paper is a notable contribution to classification of oil-bearing reservoirs, but further work is needed on the classification of oil-bearing structures.

Some additional suggestions have been made in regard to the study of oil-bearing structures which have a closer connection with the accumulation of oil and gas. Lowman suggests the need for study of the variations in the amount of closure needed for oil and gas accumulation; in the Rocky Mountains, closures up to 400 feet seem to be necessary, while in some other areas very low structures are completely filled. M. G. Cheney suggests the need for a comparison of oil-bearing structures with seemingly comparable structures that contain no oil. Does the difference lie in the structural history of the respective features, especially during the critical period of generation of the oil from the source rocks? Considerable work has been done on this subject in the mid-continent and Gulf Coast areas, but other oil provinces have probably not been studied with this problem in mind.

REGIONAL PROJECTS

Under the heading of regional projects are grouped those which deal with some one of the larger subdivisions of the continent (oil provinces, tectonic units of the first order, *et cetera.*) In general, regional projects involve the second type of research listed above—assemblage and synthesis of facts, the basic facts being derived from local studies of the

[6] W. P. Woodring, Ralph Stewart, and R. W. Richards, "Geology of the Kettleman Hills Oil Field, California," *U. S. Geol. Survey Prof. Paper 195* (1940), Pl. 51.

[7] O. Wilhelm, "Classification of Petroleum Reservoirs," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 1537–79.

sort discussed above. Most regional projects involve stratigraphy as much as they do tectonics and serve to stress the close interrelation of the two fields.

Regional projects seem to offer the most immediate promise for the discovery of petroleum. By now, most of the obvious surface indications for petroleum have been tested, and further exploration must be for less obvious structural and stratigraphic traps, the main clues to which are obtained from regional geologic relations, and from the geologic history of the region.

Some regional studies are carried on by oil companies, and large amounts of information have no doubt been summarized by them in the form of various types of maps. The writer has the impression, however, that such work is not necessarily comprehensive and that it is usually carried on incidentally to more immediate and more routine work. It would therefore seem that much of value could be accomplished by cooperative projects among oil company geologists, by study groups of local societies, by public agencies, and by other research groups. In this connection, R. A. Liddle writes:

> Such studies can best be carried on by local geological societies because most of the information is already in the files of oil companies operating in such regions. . . . Cooperation of company geologists, and sponsorship by local geological societies, should make possible the completion of a project . . . in a year or two. Projects which run through several years and administrations suffer from changing factors and interests.

5. *Geologic maps of states.*—Geologic maps of many of the states have been published, mostly on a scale of 1:500,000, and these are a valuable source of regional information. Such maps are generally assembled by plotting all available published information; adding to it manuscript maps, in part contributed by oil-company and mining geologists; and finally by reconnaissance surveys by the compiler and editor, to fill in blank spaces and to reconcile and unify the existing data.

For some states, no geologic maps have been prepared (for example, Oregon, Nevada, and North Carolina). For some of these states, so much material is now available that little more than compilation, editing, and drafting are needed. For others, such as Nevada, much more original areal mapping is needed if an adequate portrayal of the geology were to be made on the 1:500,000 scale.

Many of the existing state maps are in need of revision, as they are not on standard scale, are too generalized, or do not show the results of recent detailed surveys. Some of the older maps also do not adequately portray the structure; on the 1:500,000 scale it should be possible to show the gross fault pattern and the prominent anticlinal axes.

An example of a State map needing revision is that of Wyoming, published in 1925. This embodies much detailed published material, and many reconnaissance surveys by oil companies and others, but considerable areas were filled in from maps of the old territorial surveys, land classification maps, and other exploratory data. Subsequent to publication, detailed and reconnaissance maps have been published for many more areas, and other maps are no doubt available in manuscript. It would be desirable that the remaining, still poorly known areas be filled in by reconnaissance work.

Plans are being made by the United States Geological Survey and the State Surveys for completion and revision of the state map series, and the sub-committee on tectonics recommends that this project be completed.

6. *Geologic structure maps of states.*—Several State Surveys have published geologic structure maps of their states, which are similar in plan to the tectonic map of the United States, but on a larger scale. Such maps generally show structure contours on several horizons, faults, axes, oil and gas fields, and similar features. The geologic structure map of Kentucky is on a scale of 1:500,000, and the current edition of that of Texas on 1:1,000,000 According to J. T. Lonsdale, a revised edition of the map of Texas on a scale of 1:500,000 is nearly ready for printing and will show structure contours on 12 horizons. According to R. H. Dott, compilation of a structure map of Oklahoma is in progress; most of the state

will be contoured on the Viola limestone, but contours on other horizons will be added in certain areas. According to A. H. Bell, no comprehensive structure map of the state of Illinois is being planned, but large fractions of the state have been contoured on various horizons, much of this work being still in manuscript. A structure map contoured on the base of the Kinderhook-New Albany shale and covering about three-fourths of the state has been published.[7a]

The preparation of geologic structure maps of states by the appropriate State geological surveys is a project that deserves commendation.

In this connection, geologists engaged in exploring for zinc and lead deposits in the folded and faulted Paleozoic rocks of the Appalachian Valley in Tennessee and Virginia have indicated to the writer that a tectonic map of this area on a scale of 1:250,000 or 1:500,000 would be a great aid in their work. The occurrence of zinc and lead deposits in this area is controlled to an important degree by structural relations, and knowledge of the regional pattern is important in prospecting. All this area is covered by geologic maps, but many of these are not up to modern standards, so that extensive new surveys and a critical review of the structural features would be necessary to produce a tectonic map of real value.

7. *Comprehensive studies of regions.*—Comprehensive studies of regions involve a synthesis of all facts that will elucidate the present geological condition of a region, and its evolution through geologic time.

Studies of this type have been made ever since geologists began to wonder about the broader significance of the local features they were observing, but the results have varied widely in character. Earlier studies were based on too little information to be of value now. Many have emphasized only stratigraphy, paleogeography, or structure and have not considered the interrelations of the subjects. Many are the results of single workers, some of whom are avowedly not objective, but attempt to set forth and demonstrate a thesis. Many studies consist largely of text and lack adequate illustrative material.

The type of comprehensive study of interest to us here is the result of cooperative rather than of individual effort and is based not only on surface mapping but on subsurface work. Presentation is largely objective, the inferences not passing beyond those that can reasonably be drawn from the factual data. The results of the study appear largely in the form of maps, charts, sections, and other illustrative matter that present the data in graphic, comprehensible form. The text (if any) serves as a commentary. An example of this type of work is that of Reed and Hollister[8] in southern California. The methods employed in this work are a worth while model for further studies in the same and other areas.

Many types of plotting are possible in order to bring out the structure, stratigraphy, and paleogeography in graphic form. These include the following:

1. Contour maps on successive horizons, starting with the basement if possible, to bring out differences between successive "layers" in "layer-cake geology," or differences between important subdivisions of a single "layer."

2. Isopach maps, showing present thicknesses of "layers" in "layer-cake geology," important subdivisions of single "layers," or "stages" of the geologic systems.

3. Facies maps, showing depositional facies, especially those of tectonic significance, for each "stage" of the geologic systems. Such maps could also show (more subjectively) the nature of the adjacent lands (whether high or low), and structural features known to have been formed during the "stage."

[7a] A. H. Bell, "Subsurface Structure of the Base of the Kinderhook-New Albany Shale in Central and Southern Illinois," *Illinois Geol. Survey Rept. Inves. 92* (1943).

[8] R. D. Reed and J. S. Hollister, "Structural Evolution of Southern California," *Bull. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 1529–1692.

4. Paleogeologic maps on surface of each important unconformity.

5. Paleogeographic maps, largely combinations of the above four types, but with more subjective treatment. Presentation would be considerably more detailed than in conventional text-book maps of this type, and with main emphasis on tectonic development. Where considerable crustal shortening has taken place, this should be taken into consideration, following methods suggested by Kay.[9]

6. Charts showing time relations of orogeny, epeirogeny, transgressions, regressions, etc. in different parts of region, similar to those prepared by Reed and Hollister for southern California. In many regions such events are relatively uniform throughout the region. In others, they are variable and difficult to visualize (Tertiary of southern California, Laramide of Rocky Mountains, later Paleozoic of southern Oklahoma).

Variations of these types of plotting have been suggested by various geologists. Lowman points out that for some unconformities a map showing the geology of the surface above the unconformity would be quite as significant as a map showing the geology below it. R. A. Liddle suggests a series of maps showing the existing surface and subsurface extent of each group of strata in the region, along with the location of major tectonic features, structure contours, *et cetera*. As such maps would be confined to existing features, they would be more objective than the paleogeographic maps listed above. Perry Olcott suggests the preparation of "geodatum maps":

> What I have in mind is to slice the earth at sea level, for instance, and show the distribution of the various formations at that level. After that map is completed, step down to 1000 feet below sea level and up to 1,000 feet above sea level, and show what the areal geology of the United States would be if all the surface were removed to those levels. . . . A series of about 14 of these maps from 4,000 feet above sea level to 10,000 feet below sea level would be invaluable to geologists and mining engineers of all kinds.

No doubt other and equally ingenious methods of assembling and plotting information will occur to other geologists.

Comprehensive studies of regions can be undertaken in almost any of the oil provinces of the United States. The preliminary report of the research committee, of January, 1946, contains the following suggested projects which are related to this scheme.

1. Basin-edge structure and overthrusting in southern Oklahoma (by Ardmore Geological Society
2. The Arbuckle-Ouachita facies change (by Ardmore Geological Society)
3. A tectonic study of structures in Wyoming and adjacent states (by Wyoming Geological Association)
4. Pre-Laramide folding in Rocky Mountains (by Wyoming Geological Association)
5. The Ouachita-Marathon trend—does it exist? (by West Texas Geological Society)
6. Various problems of the Gulf Coast area, largely stratigraphic but with tectonic implications (by S. W. Lowman)
7. Various problems of salt domes (by M. A. Hanna)
8. A comprehensive tectonic and stratigraphic study of the East Texas embayment (by R. A. Liddle) (Compare with "Research Problems, East Texas Area" by East Texas Geological Society)

As pointed out by S. W. Lowman, two of the provinces offer exceptional opportunities for study, the Los Angeles area and the Gulf Coast area. Here a comparison is possible between past (Tertiary) and modern conditions and processes. In each, sedimentation possibly similar to that of the late Tertiary still continues offshore, thus making possible a correlation between processes observed in oceanographic work with processes to be inferred from outcrops and subsurface data on the land. The two regions differ considerably in character between themselves, the Los Angeles area being much more mobile tectoni-

[9] Marshall Kay, "Paleogeographic and Palinspastic Maps," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 433–42.

cally than the Gulf Coast. An opportunity is thus available for studying contrasting types of sedimentation and tectonics.

In the Los Angeles basin, according to A. O. Woodford,

> it is probable, on the basis of the foraminiferal and molluscan facies, that a large part of the basin was 5,000 to 6,000 feet deep at the beginning of the Pliocene, and that there was slow filling during the Pliocene and early Pleistocene, with local deformation but without general sinking of the floor.

This interpretation adds significance to the frequently made comparison between this Tertiary basin and the "basin and range province"[10] immediately offshore, with its deep basins, intervening platforms and ridges, and occasional islands. Research on sedimentation and tectonics leading to a comparison between the ancient and modern examples would seem to be desirable.

S. W. Lowman also discusses the need for further research upon "basin-edge structures and partly overthrust rims," with particular reference to California and the Rocky Mountains:

> These . . . would appear to be the combined result of forces generated within the sedimentary mass and the reaction of that mass to forces transmitted through the basement. Even a partial resolution of these two sets of forces should contribute to an understanding of the mechanics of deformation of the basins.

In other provinces, such as Wyoming (where the active tectonic phase was in the Mesozoic and early Tertiary) and in southern Oklahoma (where the active tectonic phase was in the Paleozoic) comparisons with modern features are more remote, but erosion has been carried to deeper levels, thus exposing features of the tectonics that are not accessible in the examples just cited.

Some oil companies are carrying on regional studies as a part of their program of oil finding. J. E. Adams describes one such project as follows.

> Right now I am working on a contour map of the basement in Texas and New Mexico with a slice of the adjoining areas. We use the U. S. G. S. base shot down to 10 miles to the inch for convenience in spotting. We are reducing the regional geophysical maps to the same scale. After I finish the basement base map, I want to use it as a vehicle for isopach, facies, paleogeology, and other projects. It should be a year and a half or two years work, even with help from the district offices. Maybe when we get there we can show the management why we favor structures in some areas and not in others. More important, we may even know why ourselves.

8. *Work of Fuels Section of United States Geological Survey.*—As a phase of the war activities of the Geological Survey, the Fuels Section, under the direction of H. D. Miser, has carried out an expanded program of oil and gas investigations. This work is still in progress. Prompt publication of results is maintained by the issuing of preliminary maps and charts. The investigations have been planned so as to supplement rather than duplicate the work done by oil companies, and much emphasis has been placed on regional studies, and on the preparation of contour and isopach maps of the sort described in the previous paragraph.

An outstanding example of the work done is a set of 7 maps and sections of the Forest City basin Missouri, Kansas, Nebraska, and Iowa. The maps show isopachs on successive stratigraphic units, and the paleogeology of the surfaces of unconformities. The sections show the progressive development of the structural features.[11] Another series deals with successive stratigraphic units in the Michigan basin,[12] and still another with a single stratigraphic unit, the Berea sand, throughout its extent in Ohio, Pennsylvania, and West Virginia.[13]

[10] F. P. Shepard and K. O. Emery, "Submarine Topography Off the California Coast," *Geol. Soc. America Spec. Paper 31* (1941), p. 9.

[11] *U. S. Geol. Survey Prelim. Map 48*, Oil and Gas Investig. Ser. (1946). 7 sheets.

[12] *Ibid., Prelim. maps 11, 17, 28, 38, and 46* (1944–1946).

[13] *Ibid., Prelim. maps 5, 9, 29, and 39* (1944–1945).

The work of the Fuels Section is to be commended, and further publications of the Oil and Gas Investigations Series will be awaited with interest.

9. *Work of Yellowstone-Bighorn Research Association.*—The Yellowstone-Bighorn Research Association has carried on a regional study in northwestern Wyoming and southwestern Montana since 1930. The methods used are different from those hitherto discussed, and deserve description for their possible application to other regions and problems. Organization of the Association is largely due to the efforts of Professor W. T. Thom, Jr., of Princeton University, who has supplied most of the data given in the following paragraphs.

Operations of the Association are a phase of University work, field work being done during the summer from headquarters at Red Lodge, Montana, and office and laboratory work during the academic year at the respective universities. Participants include faculty members of several universities (the personnel changing from year to year), graduate students working on dissertations, undergraduate students, preparatory school students, and visitors. Many phases of the structure, stratigraphy, geomorphology, and geophysics of the region are studied, but chief emphasis has always been toward obtaining a synthesis of the tectonics. As the region is one of mountain uplifts and intermontane basins in a critical segment of the Rocky Mountains, considerable contributions are possible to general knowledge of tectonics.

Most of the work consists of mapping of surface formations and structure, reports on individual units appearing in various periodicals. The United States Coast and Geodetic Survey has cooperated by establishing gravity stations in critical areas. Several summaries of the work have been published[14] and a monographic summary of the structural geology and structural evolution of the region is planned.

Work of the Association has continued on a reduced scale during the war, but plans for resumption of normal operations in the post-war period are being made. The past work of the Association is to be commended, and geologists will look forward to another fruitful period of activity on the part of the Association in the post-war period.

10. *Studies of fracture systems.*—A subject on which very little is known is the regional extent and pattern of fracture systems in the United States. The distribution of faults is fairly well shown on state geologic maps and elsewhere. The occurrence of minor breaks, or joints, generally without displacement and present both in faulted and non-faulted areas has been recorded only here and there. The writer has found that observations on joints are helpful in field work. With these observations in hand, it is apparent that faulting in an area is only half the story. Joints follow the same trends as the major faults, even miles away from them, and stray faults of odd trends prove to be the expression of widespread, important systems of jointing.

Similar revelations on a grander scale might become apparent when joint systems of a whole region are assembled. In strongly deformed or metamorphosed terranes, jointing is doubtless complex, with dips at all angles and in all directions, and with the patterns related perhaps more to local stresses than to regional forces. But in the gently dipping rocks of the vast central interior of the United States, joints generally stand nearly vertically and have systematic patterns over wide areas.

Perhaps the most comprehensive work that has been done on the regional extent of jointing is that of Melton in Oklahoma,[15] which work was later extended into adjacent states. Melton's work was avowedly reconnaissance, and although outcrops used were carefully selected, they were widely spaced. Recently, an elaborate study of jointing in 24

[14] W. H. Bucher, W. T. Thom, Jr., and R. T. Chamberlin, "Symposium: Geologic Problems of the Beartooth-Bighorn Region," *Bull. Geol. Soc. America*, Vol. 45 (1934) pp. 167–88.

———, "Results of Structural Research in Beartooth-Bighorn Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), pp. 680–93.

[15] F. A. Melton, "A Reconnaissance of the Joint Systems of the Ouachita Mountains and Central Plains of Oklahoma," *Jour. Geol.*, Vol. 37 (1929), pp. 729–46; and later papers.

quadrangles in east-central New York state has been published,[16] and also analysis of joints in two adjacent areas in West Texas with a total area of about 1,600 square miles.[17]

One possible means of filling in the character of the fractures between better known areas (at least in the arid southwest) is by use of air photographs. The writer has recently had occasion to examine a large collection of such photographs from West Texas, and has been impressed with the manner in which fracture systems are displayed, with their relations to faults, with variations in spacing and intensity, and with the setting in and dying out of different fracture systems as one proceeds across the area. Such studies, of course, give no information on the physical character of the fractures or other details; these can only be determined on the ground. But they do furnish many clues as to the regional pattern. Similar work has been done by Melton and by D. C. Barton.

Studies of fracture systems need more standardization than they now possess. More uniform rules of field procedure are desirable—how to observe and what to observe. Similarly, methods of analysis and plotting of observations need to be unified so that the large masses of observations can be summarized in understandable form, and so that observations of one worker will be comparable to those of another.

The sub-committee on tectonics would like to see the formulation of projects that would deal with fracture systems, both in their relation to local geology, and in their regional extent. Such formulation might be stimulated by the publication of more of the data that probably are now available, with attention called to problems as yet unsolved.

INTERREGIONAL PROJECTS

Interregional projects resemble regional projects in that they are largely syntheses of factual material, designed to bring out the character of tectonic features of the first order. Instead of dealing with individual provinces or regions, they deal with the continent as a whole or larger parts, hence material is assembled on a smaller scale and with a greater degree of generalization than in the regional projects. Such projects illustrate the character of oil provinces and their interrelation, and may lead to the discovery and appraisal of prospective oil provinces. Some hint of their value is suggested by the popularity of the recently published Tectonic Map of the United States.

11. *Revision of Tectonic Map of United States.*—The tectonic map of the United States was printed and issued in 1944. It was compiled and assembled by the Committee on Tectonics of the National Research Council, under the chairmanship of C. R. Longwell, and is published and distributed by the American Association of Petroleum Geologists. Much aid in the final revision of the map was also given by the Association and its affiliated societies.[18]

Since publication of the map, over half the edition of 5,000 copies has been sold. The plates have been preserved by the lithographers so that reprintings are possible. The popularity of the map has, however, suggested the desirability of a revised edition some years hence. The Committee on Tectonics is therefore being reorganized as the Committee on the Tectonic Map of the United States, and is making plans for a revision.

The main revisions will, of course, be the addition of information that has come to light since the present edition of the map was compiled. Well drilling is constantly adding new subsurface data, which will require the shifting of the structure contours as represented, or

[16] J. M. Parker III, "Regional Systemic Jointing in Slightly Deformed Sedimentary Rocks," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 381–408.

[17] *U. S. Geol. Survey Prelim. maps 2 and 8*, Oil and Gas Investig. Ser. (1944).

[18] For a history of the map project, and other information, see C. R. Longwell, "Tectonic Map of the United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (1944), pp. 1767–74.

may even suggest the need for adopting a new datum in certain areas. Much areal mapping is also in progress which may require changes in representation of the mountain areas. Thus the new geologic map of Idaho, now in press, will no doubt contain many new data of tectonic significance. A. C. Waters also points out that strategic mineral investigations by the United States Geological Survey and others in the tectonically important but poorly known Coast Ranges north of San Francisco will introduce many changes in the structural representation of that area.

In addition, reappraisal of existing information in certain areas as shown on the map would be desirable. Due to wartime pressure, the geologic publications on certain complex areas such as New England and the Canadian shield could not be as thoroughly reviewed as one might wish. Further restudy of the published material, and criticism by specialists on those areas would seem to be in order.

One possible source of information deserving exploration is the air photographs of poorly known regions that have been made by government agencies during the war. Especially helpful for obtaining a regional view are the trimetrogon pictures, taken from a high level, and including both vertical and oblique views. Much of the area in northern Mexico shown on the present tectonic map has been so covered, and the photographs of this area could be used to extend the information known from ground surveys.

In regard to revisions of the map, and preparation of similar maps, Stebinger[19] writes:

> Every geologic map is essentially a report of progress, picturing the facts known at the time of its preparation, and it is subject to corresponding limitations. This is particularly true of a compilation of this character. It is evident that the attempt to portray on a single map the orogenies of the earth's long history in their proper time sequence, over a considerable area, inevitably leads to many compromises and shortcomings in presentation. Future attempts foı the United States might well be laid out on separate maps, grouping the tectonic features leading up to, and climaxing in, each of the great orogenies. As the information increases, particularly on the superimposed orogenies buried in the basin areas, the detail will inevitably become too complex for a single map. . . . For a long time to come, American geologists must necessarily be offering revisions of their present attempt and should ultimately aim at a comparable tectonic map for North America as a whole.

Ernst Cloos, in commenting on the map, stresses the lack of detailed information (at least in many areas) and suggests that the small scale serves to hide many deficiencies:

> The tectonic map is a fine job, but in order to be really useful and to provide data on which further work can be done the scale should be larger. I should like to see somebody assembling all structural data; that is, fold axes, joints, faults, etc. on a 1:1,000,000 scale. If the scale is too small, the gaps in our knowledge will not appear and the tectonic maps of North America look unfortunately as if we knew a lot which we don't. . . . As a matter of fact, if you have ever tried to take a base like 1:1,000,000 you will immediately see that there is little you can put on. I think a project like this should bring out what we don't know as much as what we know.

This suggestion would seem to be met, at least in part, by the proposal for geologic structure maps of states that was discussed under an earlier heading (6).

12. *Related projects.*—Revision of the tectonic map implies the retention, with little modification, of the same scale, area, symbols, and method of treatment as on the present map. In addition, proposals have been made for extending the area to be covered, or for different methods of treatment. Some of these suggestions are embodied in the quotation from Stebinger, given above.

Extension of the present tectonic representation to include lands to the north and south of the continental United States would be desirable. It would not only aid in petroleum and other economic exploration, but would add greatly to the perspective in tectonics of American geologists. Many of us tend to theorize on our geology and tectonics

[19] Eugene Stebinger, "Review of Tectonic Map of United States," *Geog. Rev.*, Vol. 35 (1945), pp. 689–90.

without considering adequately the very important bearing on the subject possessed by the lands north and south of us.

Compilation of such data should lead eventually to the preparation of a tectonic map of North America, which would be a companion of the new geologic map of North America on the 1:5,000,000 scale, just as the present tectonic map is a companion of the geologic map of the United States on the 1:2,500,000 scale. This proposal may be premature at present, but as an intermediate stage, it would be desirable to begin compilation of tectonic maps of Canada, Mexico, Alaska, and other large units of the continent.

Proposals for new methods of treatment are based on one of the most serious weaknesses of the present tectonic map (at least in the contoured areas). Here, presentation tends to be selective, for only one horizon is contoured in an area. If "layer cake geology" exists, the structure of only one "layer" can be shown. Thus, in central Texas, the present map shows structure contours on the base of the Mississippian, which indicates a broad arch. Contours on the overlying Pennsylvanian would show a northwest dip, and contours on the still higher Cretaceous a southeast dip.

The solution for this problem would seem to lie in a series of maps showing present structure on different horizons, or maps showing the historical development of the structure. Maps of this type have already been described and listed under "Comprehensive studies of regions" (7). Probably the time is not yet at hand for uniform treatment of this type, covering the entire country, and the writer believes that best progress along these lines will come from studies of individual regions, as outlined under (7).

13. *Contour map of United States on top of basement rocks.*—The Special Committee on Geophysical and Geological Study of Continents of the American Geophysical Union under the chairmanship of W. T. Thom, Jr., has announced as one of its objectives in the near future the preparation of a map showing the configuration of the basement rocks in the United States. This project is to be commended.

The Committee on Continents was organized in 1935, under the chairmanship of Professor Thom, to work with two related committees of the American Geophysical Union, the Committee on Geophysical and Geological Study of Ocean Basins, and the Committee on Cosmic-Terrestrial Relationships, and with corresponding committees of the International Union of Geodesy and Geophysics. According to R. M. Field, "The personnel or membership of these committees has changed from year to year, but always with due consideration to the interrelation of the work of the three committees." In 1945, membership in the Committee on Continents was expanded, and a number of projects outlined for study, including that under discussion.

Several maps showing configuration of the basement rocks in small or large parts of the United States have been prepared and published, including one by Moss[20] in 1934, and another by the Committee on Continents in 1939, According to Thom, the history of the latter has been as follows.

> Since the seismic (refraction) method and other geophysical exploratory techniques may yield results which relate particularly to the configuration and structure of the surface of the basement complex, and since a three-dimensional model is much more easily readable than a structure contour map, one of the first endeavors of the Special Committee on Continents was to assemble a reconnaissance contour map—for the area between the Rocky Mountain front and the Atlantic Coast—in order that a "basement surface" relief model of this region could be constructed. This map and model were exhibited at the American Geophysical Union's annual meetings in April, 1936, and at the Sixth General Assembly of the International Union of Geodesy and Geophysics held in Edinburgh during the summer of 1936. Subsequently this basement map was revised and was extended westward to the edge of of Great Basin to include western Wyoming, eastern Idaho, and western Montana, and a new relief model was made—the map and model constituting, respectively, Special Exhibits 1 and 50 prepared

[20] R. G. Moss, "Buried Pre-Cambrian Surface in the United States," *Bull. Geol. Soc. America*, Vol. 47 (1934), pp. 935–66.

by the American Geophysical Union for display at the Seventh General Assembly of the International Union held in Washington in September, 1939.

A revision of these published maps would seem to be both possible and desirable. Deep wells have in recent years penetrated the basement at many more places than hitherto, and where they have not penetrated basement they have furnished data about deep-lying strata that would aid in calculating the depth of the basement. Such a map would be a useful companion of the tectonic map, in that it would reduce all the features shown thereon to a common datum. It would also be helpful for reference in geophysical work.

On any new map of this type, the writer suggests that different sorts of basement be differentiated in some manner, perhaps by different colors of contour lines. In the Central Interior Region and Rocky Mountains the top of the basement is the eroded surface of the pre-Cambrian, but elsewhere it may be of younger ages. On the west coast, if a surface could be contoured, it might be of Mesozoic age. In the Atlantic and Gulf Coastal Plains, it is the buried extension of the Piedmont surface. Proceeding eastward and southeastward from the Central Interior the top of the pre-Cambrian basement and its Paleozoic mantle is more and more deformed, and finally in the Piedmont it is deeply infolded in the metamorphic terrane, and cut off in places by Paleozoic batholiths. The surface contoured in the Coastal Plain is thus the top of a complex of pre-Cambrian and Paleozoic rocks.

W. H. Monroe points out that in the eastern Gulf Coastal Plain this surface is not reached by wells more than a short distance downdip from its outcrop, and that extrapolation is hazardous because of the seaward thickening of all the Mesozoic and Tertiary formations, and because of the marked unconformities between some of the Mesozoic groups:

> No contour map of the basement is possible in the Gulf States, except in southern Georgia and northern Florida, because of unknown thicknesses of Lower Cretaceous, Jurassic, and Paleozoic rocks.

14. *Distribution of North American geosynclines in time and space.*—The study of geosynclines is mainly stratigraphic, but deserves mention here because of its tectonic implications. Study of North American geosynclines has been given new impetus in recent years by Kay[21] who has subdivided geosynclines into five types, and who points out that in geosynclinal belts the different types may be superimposed on each other in many arrangements. With the aid of these new concepts, it is desirable that the time and space relations of the different types be determined, and Kay has been working on a series of sequential maps on which the extent of the different types of geosynclines is indicated.

GEOPHYSICAL PROJECTS

Research in geophysics is being discussed by a sub-committee on that subject, but it seems worth while at this place to discuss briefly projects leading to results in tectonics which must be accomplished largely by geophysical methods.

15. *Gravimetric map of United States.*—The United States Coast and Geodetic Survey has from time to time published maps showing variations in the value of gravity in the United States. Such maps have been based on pendulum stations, for the most part widely spaced, and set up to aid in determination of the best parameters of the spheroid of reference to be used in the reduction of the triangulation network.

Much more detailed work has been done in parts of the country, partly by increasing the density of the pendulum stations, and partly by gravity meter traverses. M. K. Hubbert suggests that similar treatment be extended to the remainder of the country. This project is summarized as follows.

> Increase of density of gravimetric base stations to one station to 2,500 square miles; interconnect

[21] Marshall Kay, "Geosynclines in Continental Development," *Science* (June 9, 1944), pp. 461–62; and subsequent papers.

pendulum stations with gravity meter traverses and adjust network to 0.1 milligal accuracy; run gravity meter profiles across major second-order gravity anomalies and across major tectonic features of the United States.

This project is recommended by the research committee.

16. *Magnetic map of the United States.*—A similar map might be prepared, showing in more detail than hitherto the variations in the value of magnetism in the United States. As Hubbert points out, use of the airborne magnetometer will greatly increase the rapidity with which the basic data could be assembled.

17. *Tectonic data from level lines and triangulation nets.*—Level lines and triangulation nets of the United States Coast and Geodetic Survey furnish one of the main clues as to deformation now in progress in the United States. Further collaboration between geologists and this Survey, and use of the Survey's results by geologists would be desirable. In this connection, James Gilluly makes the following comment.

Many useful tectonic data are contained in the U. S. Coast and Geodetic Survey level lines, especially in California. Many of these lines have been run over again at intervals of some years, and the original field notes show significant differences in the vicinity of folds and faults. These differences are generally smoothed out or eliminated in final calculations and adjustments. It is suggested that both adjusted elevations and original field elevations be made available for use of students of tectonics.

18. *Oceanographic studies.*—Mention has been made that in our thinking regarding tectonics in the United States we often tend to ignore the effects of the tectonics of the lands to the north and south of us. Another "blind spot" in our thinking is the submerged offshore areas. Here, because the geology and tectonics can not be worked out by direct observation, recourse must be had to various geophysical methods.

The importance of such work to tectonics is illustrated by the revolutionary discovery of Meinesz[22] that the axes of mobile belts at sea are characterized by large negative anomalies. Equally interesting are the studies of submarine canyons, although their tectonic implications are more remote. To petroleum geologists, chief interest attaches to studies of the continental shelves, which are widely believed to contain large reserves of oil. Exploration of the geology of the continental shelves would seem to have practical as well as theoretical interest.

One of the most promising investigations of the continental shelves so far made is that of Ewing and others[23] off the Atlantic coast. Two seismic cross sections were made, starting on land and extending 100 miles or more seaward. The results indicate the configuration along the lines of the cross sections, of the surface of the crystalline basement rocks, and the relations of overlying semi-consolidated and unconsolidated rocks. It is reported that further work of this type has been done for government agencies during the war, and J. A. Sharpe states that various oil companies plan to make geophysical studies of the shelf areas in the course of their exploration for petroleum.

GENERAL AND THEORETICAL PROJECTS

Consideration will now be given to projects involving the third type of research in tectonics—research leading to the interpretation of facts. The reader will recall a plea by Hubbert, quoted earlier in this report, calling for study and experimentation (as opposed

[22] F. A. Vening Meinesz, "Marine Gravity Survey in the Netherlands East Indies: Tentative Interpretation of Provisional Results," *Proc. Kon. Akad. Wetensch.*, Vol. 33, pp. 566–77. Amsterdam (1930).

———, "Gravity Anomalies in the East Indian Archipelago," *Geog. Jour.*, Vol. 77 (1931), pp. 323–49.

And other papers.

[23] Maurice Ewing and others, "Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 753–812.

to mere speculation) on the origin of structural features, making use of mechanical and other principles that have been developed in the physical sciences.

This section of the report is shorter than those which have gone before. This is not because the writer is out of sympathy with this type of work, but partly because his knowledge of it is slight, for his training and interests (like those of many other geologists) have been in fact-finding and synthesis. Also, the subject has been well covered in a report of the National Research Council by a sub-committee of the Interdivisional Committee on Borderland Fields between Geology, Physics, and Chemistry.[24] Parts of this report are here quoted, but for further information the reader is referred to the original.

General nature of the problem.—The general nature of the problem is summarized as follows by the Research Council sub-committee.[25]

The study of the deformation of rocks is but one division of the general subject: the mechanics of deformable bodies. The mechanics of fluids is another branch of the same subject. The mechanics of deformable bodies, far from being in its infancy, has been cultivated with ever increasing intensity for somewhat more than a hundred and fifty years, first by the physicists and more recently by the engineers, particularly in the field of hydrodynamics, aerodynamics, and soil mechanics. During that time methods of experiment and of description and analysis have been evolved which have proved indispensable to students of the various branches of the subject. . . .

An understanding of rock deformation is a matter of fundamental importance to geologists. Rock deformation is a physical phenomenon, however, and if one is to proceed to its study beyond the stage of elementary description the language and the tools developed by the physicist for problems of this kind are indispensable.

On the purely mechanical side of the problem, the study of deformations consists principally of two stages (1) an accurate description of deformation and (2) a dynamic study wherein the forces accompanying the deformation are taken into account. In addition to these there is a thermodynamic aspect of the problem, particularly in those cases in which the materials being deformed undergo changes in phase during the process. The latter is a common phenomenon accompanying deformation of rocks, leading to the mineral changes of the sort occurring in dynamo-metamorphism. . . .

There is great need for field studies of regional deformations employing these more precise methods of analysis and description. Such studies should embrace both contemporary deformation and strains that occurred in the past. The data must be obtained from the field; the methods of description and analysis have already been perfected. . . .

The logical approach to the problem seems to require the following major steps:

1. Become familiar with the methods of analysis and experiment that are used successfully in the related fields of elasticity, plasticity, soil mechanics, and fluid mechanics.

2. Borrow as much of this as is applicable to the problem of rock deformation and apply it to existing geological field and laboratory data on rocks. This should enable one to evaluate the adequacy of existing data and show precisely what new data are needed most.

3. In the light of this evaluation, obtain from the field and from the laboratory the further data required, and repeat the solution.

19. *Field projects.*—The Research Council sub-committee lists the following classes of field projects as deserving study.[26]

1. Regional determinations of the kinematical elements of contemporary strains as in (1) regions undergoing orogenic movements (such as southern California), and (2) regions undergoing epeirogenic movements such as the post-glacial uplift. (It is suggested that the analysis of such movements be carried out by analytical methods applicable to vector fields. . . .) The field methods to be used vary with the different problems. They include periodic repetition of precise triangulation and level networks, tide gauge stations, shoreline studies, tilt meters, and integration of strong earthquake records. . . .

2. Measurements of local elastic strains of rocks in quarries and excavations by means of strain gauges, and analysis of measured strains to obtain magnitude and orientation of stress tensor.

[24] M. K. Hubbert, W. H. Bucher, D. T. Griggs, and A. Nadai, "Deformation and Rupture of Geological Materials; Report of Sub-Committee on Rock Deformation," in *Report of Interdivisional Committee on Borderland Fields between Geology, Physics, and Chemistry*, Nat. Research Council, Div. of Geol. and Geog. (1938), pp. 12–20.

[25] *Ibid.*, pp. 12, 14, and 17.

[26] *Ibid.*, pp. 18–19.

3. Regional mapping of past geologic strains by methods applicable to vector fields: a) mapping of strains, b) Determination of unstrained state. . . .
4. Field mapping of flow lines, foliation, joints, etc. . . .

Some of these projects resemble or duplicate those suggested earlier in this report. Thus, item 1 includes project 17, tectonic data from level lines and triangulation nets. Item 4 includes project 3, detailed study of salt domes; project 4, detailed study of other oil-bearing structures; and project 10, studies of fracture systems.

Mention should be made here of research in petrofabrics, or the detailed field and microscopic study of mineral orientation in rocks, and explanation of it as in part due to deformation. Most research on the subject is not of interest to the present sub-committee, as it deals mainly with igneous and metamorphic rocks, and with rocks that have been thoroughly recrystallized and reconstituted. However, some work in the petrofabrics of moderately deformed sedimentary rocks has been done by Ernst Cloos and his students[27] and deserves consideration. The rocks studied are in the folded belt of the Appalachians, but in the absence of petrographic analysis would not impress the observer as having suffered much internal change. However, study of oolites in the limestones and quartz grains in the quartzites indicates that much flowage has taken place.

20. *Laboratory experiments.*—The purpose of laboratory experiments is indicated as follows by the Research Council sub-committee.[28]

> In many problems formal analysis from known data, even though allowing of a unique solution, would involve one in hopeless mathematical difficulties. In such instances we may resort to another physical tool—the theory of dimensions—which tells us how to build a model that will perform like the original and will consequently enable us to get an answer experimentally which might be unobtainable otherwise. Although precision of data in such cases is always desirable, it is frequently irrelevant whether the data are correct to two significant figures or to seven.

The Research Council sub-committee outlines the following classes of subjects as deserving study:[29]

1. Measurement in the laboratory of the elastic, plastic, and viscous properties of rocks and minerals with temperature, time, presence of volatiles, and stress as independent variables
2. Experimentation by means of dimensionally correct scale models of geologic features. (The methods of experiment being developed in soil mechanics contain many features of use in geological experimentation)
3. Study of stress distribution in geologic features by application of photoelastic technique to dimensionally correct scale models. . . .
4. Experimental investigation of orientation of particles due to plastic deformation
5. Experimental investigation of fracture, cleavage, and faulting. One very important problem here is the orientation of the systems of fracture and cleavage
6. Petrofabric analysis of artificially deformed rocks. . . .
7. Study of the flow of salt

The status of experimental work in tectonics is summarized as follows by Hubbert:[30]

[27] Ernst Cloos, "Distortion of Stratigraphic Thicknesses Due to Folding," *Proc. Nat. Acad. Sci.*, Vol. 28 (1942), pp. 401–07.
R. E. Fellows, "Recrystallization and Flowage in Appalachian Quartzites," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 1399–1432.
Ernst Cloos, "Lineation; a Critical Review and Annotated Bibliography," *Geol. Soc. America Mem. 18* (1946), pp. 43–45.

[28] M. K. Hubbert, W. H. Bucher, D. T. Griggs, and A. Nadai, *op. cit.*, . . 17.

[29] *Ibid.*, p. 19.

[30] M. K. Hubbert, "Strength of the Earth," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 1651–53.
See also, ———, "Theory of Scale Models as Applied to the Study of Geologic Structures," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 1459–1519.

For more than a century and a quarter attempts have been made to simulate the formation of mountains and other tectonic structures by means of small scale models. In the preponderance of such cases the materials used have consisted of hard waxes, stiff clays, partially cemented sands, plaster of paris, and similar substances, and the results have been indifferent at best. Typical and among the better known of such experiments are those made by Bailey Willis in his classical study of the folding of the Appalachian Mountains. Willis constructed models of about a meter in length representing the unfolded strata of the Appalachian geosyncline. These were compressed longitudinally into structures simulating those of the Appalachian Mountains. . . .

If one of Willis' models were to be regarded as representing an Appalachian section of about 100 kilometers in length the overburden used would be equivalent to 150 to 300 kilometers of rock. Even then the more rigid strata broke into discrete slabs and open cavities appeared. The Appalachians had no such overburden, but were held down solely by their own weight, yet the folding in the most rigid strata was continuous and no open cavities were formed. Hence it must be concluded that the rocks of the Appalachians in respect to their environment were much weaker than the materials used by Willis, or conversely, that Willis' materials were much too strong to represent the Appalachian Mountains.

As remarked before, the materials used and the results obtained by Willis are typical of most of the model experiments upon geologic structures which have so far been performed. Notable exceptions occur in the cases of some experiments performed by Koenigsberger and Morath about 1912, and in the later 1920's by Hans Cloos. . . . Cloos reasoned simply that if an original geologic feature were composed of rocks strong enough to support a column 10 to 20 kilometers high, a model with a length reduction of 1/50,000 should be capable of supporting a column 1/50,000 as high, or 20 to 40 centimeters. On this basis he then selected soft, half-liquid clay as his experimental material. With this he has been able to obtain some of the most accurate duplications of a wide variety of geologic structures which have so far been achieved.

Better known to the oil fraternity are the experiments of Nettleton wherein salt dome formation has been represented by means of viscous fluids of contrasting densities. While not accurate in all details, these experiments of Nettleton afforded a far more convincing demonstration of the mechanics of salt-dome formation than any previous attempts.

Recently a model experiment has been described by Griggs for the demonstration of the hypothesis of mountain folding by deep-seated convection. The model parameters of that experiment were determined in accordance with the theory as developed by the present writer (Hubbert). The results were in remarkable accord with the major tectonic features of many existing mountain ranges.

This discussion indicates that the whole field of experimental work in tectonics needs reconsideration in the light of new concepts, and that many experiments that have been made in the past should be done over, using much weaker materials.

In regard to experimental work, Ernst Cloos writes:

My brother (Hans Cloos) has made many domes and the experiment is rather simple to repeat. It may well be that such an artificial dome is not exactly a natural one, but the experiments are very suggestive and we have learned a lot by performing them. One can either approach a definite problem in the field and experiment with the problem in mind, or one can perform experiments and verify the findings in the field. Either approach is fruitful and if there would be a call for it, I would be most willing to teach others what to do. I have at present little time to work in that direction systematically, but have for teaching purposes frequently dusted off my equipment and used it. . . . My equipment is now good and could easily improve with very little cost. The cost of that sort of experimental work is almost negligible.

James Gilluly writes:

We are now in the process of organizing an institute of geophysics here at U.C.L.A. and when that is done, I am going to try to get the help of competent geophysicists in some model work. I believe there is a considerable contribution possible there, but I certainly don't know enough geophysics to do it myself. On the other hand, very few geophysicists know enough geology to do it by themselves. Maybe a team could get somewhere.

L. L. Nettleton writes:

The experimental work which I have done in the past has been limited to the fluid salt dome models and has been published in the *Bull. Amer. Assoc. Petrol. Geol.* (Sept., 1934 and Jan., 1943). More recently, I have been doing some preliminary experiments designed to investigate faulting with special reference to that which occurs around salt domes and the rather common situation of having faults in the sediments above domes, for which the downthrown side is towards the dome, rather than away from it, as might be expected from simple considerations. To the extent that the work may be

successful in showing the mechanics by which such faults are formed (a stage which has not yet been reached), this work might be considered as an attempt to solve a specific practical problem. . . . However, it is hoped that along with it, much more general and theoretical questions may be considered.

A primary factor in all of this work has been to keep in mind as much as possible the dimensional factors involved in these model studies along the lines pointed out by Hubbert. Incidentally, I should remark that the work which I have done is only as a rather occasional sideline of my primary duties, and therefore has had rather irregular and intermittent attention on my part.

The results of the recent experimental work noted above were presented by Nettleton at the 1946 meeting of the American Geophysical Union. In discussing the use of motion pictures in geological education, Nettleton suggests the desirability of having:

. . . a short film made of the Cloos clay models. I understand that such a film was made in Germany but is not available here. It is my own feeling that a few hundred dollars spent to make such a film or to acquire it, if already made, and then making this film available for loan to local geological societies and schools would so dramatize many features of structural geology that it would have a real influence on thinking along these lines.

T. A. Link writes:

If I were teaching a course in structural geology I would devote considerable time to laboratory studies for all the students wherein they would are required to do some of the more elementary experiments. I am firmly convinced that any geologist who has devoted some time to such experimental work, no matter how simple, has gained a considerable advantage over those who have not. . . . However, for advanced structural research, something more elaborate than that must be considered.

The establishment of a laboratory in which there is available a work or machine shop, high and low temperatures and pressures, compressed air, power, etc., is my idea of an ideal setup for serious experimental research in structural geology and tectonics. . .. I have always had a hankering to be able to go into a first-class laboratory where everything would be available, where things could be built with precision tools and experiments were conducted under controlled conditions. This applies not only to the apparatus itself but to the materials used.

There are so many problems of regional structural study which might be studied in the laboratory from which one or two ideas might be forthcoming. We now have in our universities and for industry, laboratories for Chemistry, Physics, Geophysics, etc. fully equipped, but I know of no first-class laboratory for structural and tectonic geology. (There may be some, but I am not aware of it). Such laboratories would naturally have to be manned with skillful technicians, guided by geologists with ideas and, above all, with enthusiasm.

Mrs. E. B. Knopf[31] proposes a study of experimentally deformed rocks, starting first with single crystals, and proceeding to monomineral rocks, and finally to polymineral rocks. Such a study is concerned more with the minutiae of rock deformation than with the larger features, but would certainly influence thinking in many phases of tectonics.

The sub-committee on tectonics feels that experimental work on the subject is of fundamental importance, and would like to see specific projects formulated and proposed in this type of work.

ACCESSORY ITEMS

A number of other items deserve consideration which, while not research, are useful tools and aids to the research worker.

21. *Definitions.*—The terminology of structural features, although discussed at length in many text books and the subject of decisions by many committees, continues to be a matter of debate in geological periodicals. This is partly due to loose thinking on the part of geologists, and the difficulty of a geologist in mastering voluminous terminology in more than a few specialties. It is also because terminology is inevitably linked to geological concepts, and as these concepts change, or new concepts arise, changes and additions in terminology are necessary. Probably it will be necessary from time to time to systematize our terminology by the further work of committees.

[31] E. B. Knopf, "Postwar Study of Experimentally Deformed Rocks," *Trans. Amer. Geophys. Union*, Vol. 26, (1945), pp. 303–04.

Ralph L. Miller writes:

A committee on definitions seems to me highly desirable to set up standards of usage for structural terms. One need only point to the extreme confusion that now exists in the literature on usage of the terms reverse fault, thrust fault, and overthrust fault to show the desirability of standardizing and publicizing structural nomenclature.

Another type of terminology is that of the specific names of individual structural features. No one would probably wish to standardize these as rigidly as stratigraphic or zoologic names, but in some places confusion has arisen because different names have been used for the same feature. This became apparent in the editing of the Tectonic Map of the United States, and for this many arbitrary decisions had to be made, some of which will probably require revision. Supervision of the standardization of names for specific structural features could be well undertaken by the respective State Surveys.

22. *Base maps.*—Several geologists interested in tectonics have expressed the wish for more adequate base maps on scales of 1:1,000,000 and 1:500,000 for use in plotting information. A similar wish on the part of geophysicists has been expressed by M. K. Hubbert, and it is no doubt shared by geologists and geographers working in other fields.

Base maps on a scale of 1:500,000 by the United States Geological Survey are available for all the states, but these do not show relief features and if the plotting crosses state boundaries several maps must be cut out and fitted together. Some other system of maps, with lines of division along meridians and parallels, would be more satisfactory for many purposes.

A useful series, when completed, will be the sheets of the International Map of the World, on a scale of 1:1,000,000. Of the 70 sheets required to cover the United States, five have so far been published by the United States Geological Survey, and six more are reported to be nearly ready for publication. The writer has found the similar series—the Millionth Map of Hispanic America—to be very useful for plotting tectonic and other geologic information. Tracing material is laid over the sheet; orientation is provided by the drainage, towns, relief, and coordinates; and the data are marked on the overlay.

A similarly useful series are the air navigation charts of the United States published by the United States Coast and Geodetic Survey, one group on 1:1,000,000, and another on 1:500,000. The copies for general distribution are overprinted with air navigational data, of no value for the present purpose, but copies without the overprint are available on request. The maps show enough relief, drainage, and cultural features to guide the user without being cluttered, and are divided into 15-minute coordinates that are very useful for plotting.

23. *Bibliographies and abstracts.*—Ernst Cloos contributes the following discussion.

Bibliographies and abstracts are extremely useful and I would like to add that the systematic review of a problem and assemblage of all the literature plus a critical discussion can do a great deal to inform the interested geologist and save him immense amounts of time. I have just now in print a critical discussion and bibliography on lineation.[32] . . . I have 375 literature references, all annotated and ranging from 1832 to 1943. I hope that such a review and compilation will be handy for many who cannot go into it as I did and don't need to if my work is sufficiently full and accurate. A similar bibliography on faults has been planned, but I have not gotten to it yet. . . .

Such compilations are drudgery but extremely useful if done well and in years to come it will be absolutely impossible for the student that begins today to be fully informed on the literature because the literature grows at such a rate that even those who have a head start, like we ourselves, can't keep up with it. The field I can keep up with grows smaller and smaller, simply because I can't keep up with all I started with. I therefore feel that some of the older men that are qualified to do so should contribute about a year of their time to one such compilation which will then be a handbook, not necessarily containing all the information, but certainly containing all the literature references, and if at all possible, annotated so that it becomes possible to see what the author was driving at . . . and what his conclusion is.

[32] Ernst Cloos, "Lineation; a Critical Review and Annotated Bibliography," *Geol. Soc. America Mem. 18* (1946).

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

PETROLEUM PRODUCTION ENGINEERING, BY LESTER CHARLES UREN

REVIEW BY HARRY H. POWER[1]
Austin, Texas

**Petroleum Production Engineering—Oil Field Development.* New Third Edition (1946). By Lester Charles Uren. 764 pp., 321 figs. Cloth. 6×9 inches. McGraw-Hill Book Company, Inc., New York. Price, $7.00.

The new third edition of *Petroleum Production Engineering* by Lester Charles Uren, professor of petroleum engineering at the University of California, presents a complete, systematic, and well balanced treatment of petroleum production engineering through all the phases of oil-field development and up to the point at which the wells are ready to produce. Most of the material of prior editions has been re-written by the author and many new features covering recent developments in the technology of oil-field practice have been added.

Beginning with chapters devoted to the properties and occurrence of petroleum in nature, petroleum exploration methods, and principles of oil-field development, the author discusses in detail the operations of drilling and equipping wells. Succeeding chapters are devoted to the occurrence and behavior of water in sedimentary strata, the identification of water-yielding formations in drilling, and methods of excluding water from wells. Fishing tools and methods of fishing, well-completion methods, well records, logging methods, surveys, and inspection of formation samples are the concluding chapters of this book.

In view of the increased attention paid to problems in reservoir engineering, the two concluding chapters are of particular interest currently. An excellent summary of modern correlation methods, including geological, electrical, radioactive, geochemical, temperature, drilling-time, and caliper logging is presented for ready reference of student or the busy engineer and geologist in industry who may wish to review these subjects in an orderly manner. Likewise, the final chapter gives a well organized discussion of the various laboratory methods for the inspection and testing of formation samples. The methods specifically discussed are: extraction, identification, and determination of fluid content of core samples; porosity and permeability determinations; size distribution of granular components of formation samples; concentration and identification of microfossils in formation samples; and methods of displaying results of core inspection and analysis.

The unusual task presented in culling out of the voluminous petroleum literature of today those features of practical interest to the student, practicing engineer, geologist, or executive, has been pursued by the author for many years. Few readers grasp the enormousness of this task. Reference to the most excellent bibliography at the end of each chapter (which alone is worth the price of the book) should convince anyone, on somber reflection, that Charles Lester Uren, through the years, has performed a service that the educational institutions and industry alike should give full and well deserved recognition.

[1] Professor of petroleum engineering, the University of Texas. Review received, October 21, 1946.

GEOLOGÍA DE BOLIVIA, BY F. AHLFELD

REVIEW BY NORMAN D. NEWELL[1]
New York, N. Y.

"Geología de Bolivia," by Federico Ahlfeld, Instituto del Museo de la Plata. *Revista del Museo de la Plata*, t. 3, Geología, No. 19 (May 18, 1946). 370 pp., 115 figs., with colored geological map of Bolivia, scale 1:212,000.

The appearance of this important memoir will be enthusiastically hailed by all students of Andean geology. The "Geología de Bolivia" is Ahlfeld's ***magnum opus***, for which he has been gathering data ever since he first went to Bolivia in 1923. In 1935 he became chief geologist for the Dirección General de Minas y Petróleo, an important post which he has occupied until the present year.

With admirable courage and determination he has labored unfalteringly and almost alone, while sorely handicapped by what most European and American geologists would regard as the most limited funds and inadequate working facilities. It is with regret that we learn that Ahlfeld's work in Bolivia comes to a close with the publication of his book.

After paying appropriate respects to the great pioneers of Bolivian geology, d'Orbigny, Steinmann, Kozlowski, and many others, Ahlfeld indicates, in the first chapter, the extent of his own travels and observations in Bolivia, which certainly exceed those of any other geologist.

In subsequent chapters the author discusses the main geologic regions of Bolivia: the Oriente, or eastern lowlands, the sub-Andean area, the Eastern and Central Cordilleras, and the high plateau, together with the Western Cordillera. Chapters are devoted to the Quaternary geology, orogenesis, geologic history, mineral deposits, and seismology.

A regional geological map of the Bolivian Andes, covering much of the Republic, accompanies the memoir. The author wisely leaves blank several large areas as "*inexplorado*."

The stratigraphic column includes Cambrian, Ordovician, Gotlandian (Silurian), Devonian, Permo-Carboniferous (Lower Permian), continental Permian, Cretaceous (mainly continental), and continental Tertiary and Quaternary. Twenty different divisions are indicated on the map, as are many great overthrusts and normal faults. This map, as Ahlfeld clearly states, represents a compilation of all available data, collated and revised in terms of his own observations. No claim is made that it is the "first" geological map of the country, since that distinction belongs to a map published over a century ago by d'Orbigny. A second map by Leonardo Olmos, based largely on the early map appeared in 1912.

In an admirably restrained statement (footnote, p. 352) Dr. Ahlfeld notes that a geological map of Bolivia published in 1944, by V. Oppenheim, was based directly on the manuscripts and preliminary maps made available to him, in good faith, during a visit to La Paz, in 1942. The reviewer learned the source of Oppenheim's data directly from that author, who felt no need for hesitancy in publishing the map without authorization, since he had modified it in some respects, adding original data of his own. The Geological Society of America received a manuscript copy of Ahlfeld's map, in essentially its final form, as early as 1943.

The Geología de Bolivia is so packed with data, many of them herein published for the first time, that an adequate digest will not be attempted in this review. Two salient facts are of interest to the reviewer, however. It is evident that the histories of the Eastern and Western Cordilleras were quite different, as is also the case in southern Peru. All of the Paleozoic rocks in Bolivia lie in the Eastern ranges, whereas the vast volcanism of the region essentially is confined to the Western Cordillera and to the Altiplano.

[1] Curator of historical geology and fossil invertebrates, American Museum of Natural History; professor of geology, Columbia University. Review received, October 21, 1946.

The Corocoro group, of probable early-medial Tertiary age, occupies the southwestern part of the Altiplano. In southern Peru these beds (Puno group) overlap early Cenomanian marine beds, resting locally on the Devonian. These Tertiary deposits are enormously thick continental redbeds, containing much coarse volcanic material, clearly indicating orogeny, probably Laramide, followed by rapid subsidence and volcanism. Paralleling the Corocoro group in the near-by area of the Eastern Cordillera of Bolivia, is the Puca group. Over great areas the Puca group is gradational from Senonian marine horizons upward through the early Tertiary, and the Mesozoic-Cenozoic boundary can be recognized only with considerable difficulty. One is led to conclude that Laramide folding was confined to the Western Cordillera and the Altiplano, whereas sedimentation in the Eastern Cordillera was interrupted, if at all, only by epeirogeny.

After deposition of the Corocoro group the region experienced the principal folding of the Andes. The Corocoro beds contain a fossil flora, and since they are the youngest tightly folded deposits in northern Bolivia their age assignment figures importantly in dating the last orogeny.

Ahlfeld believes that a Pliocene age for the Corocoro beds, as specified by Berry, gives too recent a date for the folding of the Andes and, consequently, he is disposed to conclude that the fossil flora and the folding of the region is more probably Miocene or perhaps even older, a view which was held by Steinmann and by Kozlowski. The reviewer is inclined to endorse this general conclusion, perhaps following slightly different logic. Fossil floras of the late Tertiary are commonly believed to reflect environmental facies more than absolute age, so that precise dating of sediments by means of these floras is very difficult. An extremely important fact, which should have been given greater emphasis by Ahlfeld, is that the folded Corocoro group is truncated by the upland peneplain described by Bowman, McLaughlin, and others. The great volcanic cover of the Western Cordillera rests nearly horizontally on the old erosion surface. The volcanics contain interbedded Pliocene (or Miocene?) fossils (Mauri formation) in Bolivia. Miocene (?) and Pliocene marine faunas near Icla, on the Peruvian coast appear to rest on an old erosion surface, which may correspond with the great upland peneplain. It seems unlikely that the Pliocene alone would suffice for the folding of the Andes and their subsequent peneplanation, followed by deposition of a considerable part of the later volcanics. To the reviewer it seems more likely that the orogenic cycle was completed no later than the Miocene, and possibly was begun even earlier.

Ahlfeld's book is well illustrated by numerous original sections, maps, and sketches, and by many of the author's excellent photographs, for which he is justly noted.

Without intent to detract from the great value of this work it is pertinent to note that numerous typographical errors occur here and there throughout the book. The halftone cuts, which appear to be of high quality, would have resulted much better on a good coated paper.

Ahlfeld's own estimation of his work indicates an appreciation of its limitations.

> I beg of all my colleagues that they keep in mind, while criticizing this work, that it endeavors, for the first time, to touch on the collective geological problems of Bolivia. It is realized that this attempt will present many shortcomings. Likewise, it must be said that the geological map . . . will be subject to many corrections in the future. It was my intention to offer, by means of the book and the map, a review of all our present knowledge over the geology of Bolivia, based on existing publications, and on my own new observations. It is my chief hope that they serve as a base for future geological investigations in Bolivia.

RECENT PUBLICATIONS

ALABAMA

"Geologic Map of Tuscaloosa and Cottondale Quadrangles, Alabama, Showing Areal Geology and Structure of Upper Cretaceous Formations," by L. C. Conant, D. H. Eargle, W. H. Monroe, and J. H. Morris. *U. S. Geol. Survey Prelim. Map 37*, Oil and Gas Investig. Ser. (October, 1946). Map, scale 1 inch equals 1 mile, covers 500 square miles. Geology, subsurface structure contours on Paleozoic rocks and on Cottondale, Eoline, and Coker formations of Tuscaloosa group; also, text and detailed graphic section of Tuscaloosa. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.55.

APPALACHIANS

*"Appalachian Drainage and the Highland Border Sediments of the Newark Series," by C. W. Carlston. *Bull. Geol. Soc. America*, Vol. 57, No. 11 (New York, November, 1946), pp. 997–1032; 3 pls., 1 index map.

ARGENTINA

*"Contribución al Conocimiento Geológico de la Precordillera Sanjuanino-Mendocina" (Contribution to geological knowledge of the pre-Cordillera of San Juan and Mendoza provinces), Part 5, by Osvaldo Bracaccini. *Bol. Inform. Petroleras*, Vol. 23, No. 263 (Buenos Aires, July, 1946), pp. 22–35; 4 cross sections, 4 photographs. In Spanish. (Parts 1–4 published in Nos. 258, 260, 261, and 262 of *Bol. Inform. Petroleras.*)

CALIFORNIA

*"Classification of Oil Discoveries and Fields," *Anonymous. Petroleum World*, Vol. 43, No. 11 (Los Angeles, November, 1946), pp. 72–75. Report of Classification Committee (Frank S. Parker, chairman) of Pacific Section, A.A.P.G. Includes detailed schedule of California field and pool names prepared by joint committee of Pacific Section, A.A.P.G., and Conservation Committee of California Oil Producers.

*"Submarine Photography off the California Coast," by F. P. Shepard and K. O. Emery. *Jour. Geol.*, Vol. 54, No. 5 (Chicago, September, 1946), pp. 306–21; 1 index map, 1 bottom-sediment chart, 28 photographs.

COLORADO

"Subsurface Maps of the Rangely Anticline, Rio Blanco County, Colorado," by N. W. Bass. *U. S. Geol. Survey Prelim. Map 67*, Oil and Gas Investig. Ser. (October, 1946). Single sheet, 32×44 inches. Map of the Rangely oil field shows structure contours drawn on top of the oil-producing Weber sandstone; other maps show the thickness of the redbeds above the Weber sandstone, and the thickness of all the rocks between the Dakota sandstone and the Weber. Diagrams and explanatory text included. Mail orders should be sent to the Director, Geological Survey, Washington 25, D. C. Price, $0.25.

*"Rangely Faults—Good and Bad," by S. M. Newton. *Oil Reporter*, Vol. 3, No. 18 (Denver, October 22, 1946), pp. 8–11, 27; illus.

EUROPE

*"The Geological Structure of East Poland and West Russia: A Summary of Recent Discoveries," by Zbigniew Sujkowski. *Quar. Jour. Geol. Soc. London*, Vol. 102, Pt. 2, No. 406 (London, July 31, 1946), pp. 189–201; 2 figs., 2 tables, 1 geologic map, list of references.

*"The Natural Steam at Larderello, Italy," by W. D. Keller and Adriano Valduga. *Jour. Geol.*, Vol. 54, No. 5 (Chicago, September, 1946), pp. 327–34; 3 tables, 4 figs. Description and report of utilization of emanations delivered through fractures from probable batholith freezing beneath.

GENERAL

*"Trimetrogon Aerial Photography," by Ralph W. Disney. *Oil and Gas Jour.*, Vol. 45, No. 24 (Tulsa, October 19, 1946), pp. 113-15; 4 figs., 3 photographs. Description of a wartime development of the science of photogrammetry, credited to the Alaskan Branch, U. S. Geological Survey.

*"Radioactivity Well Logs—Interpretation and Application. Part 1, Gamma Ray Curves; Part 2, Neutron Curves; Part 3, Combination Radioactivity Logs," by V. J. Mercier. *Oil Weekly*, Vol. 123, No. 7 (Houston, October 14, 1946), pp. 56-60; 7 figs.

**Ibid.* "Part 4, Correlation with Other Type Logs; Part 5, General Considerations; Part 6, Conclusion," by V. J. Mercier, Vol. 123, No. 8 (October 21, 1946), pp. 41-46; 7 figs., references.

*"Temperature Well Logging. Part 1, Heat Conduction," by Hubert Guyod. *Ibid.*, pp. 35-39; 9 figs., 2 tables.

**Ibid.* "Part 2, Salt Intrusions," Vol. 123, No. 9 (October 28, 1946), pp. 33-42; 14 figs.

*"Influence of Clay Content on Water Conductivity of Oil Sands," by T. F. Bates, R. M. Gruver, and S. T. Yuster. *Oil Weekly*, Vol. 123, No. 8 (October 21, 1946), pp. 49-50; 5 figs. Results of a study of the clay minerals associated with the Bradford oil sand, employing (1) differential thermal analysis, (2) X-ray spectrometer, and (3) the electron microscope.

*"The Performance of Bottom Water-Drive Reservoirs," by Morris Muskat. *Petrol. Tech.*, Vol. 9, No. 5 (New York, September, 1946). 31 pp., 20 figs. *Amer. Inst. Min. Met. Eng. Tech. Pub. 2060.*

*"A New Well-Completion Technique," by T. S. West. *Petrol. Tech.*, Vol. 9, No. 5 (New York, September, 1946). 17 pp., 9 figs., 1 table. *Amer. Inst. Min. Met. Eng. Tech. Pub. 2094.*

*"Grado de exactitud de los métodos de exploración para petróleo" (Accuracy of Methods of Petroleum Exploration), by Juan J. Zunino. *Bol. Inform. Petroleras*, Vol. 23, No. 263 (Buenos Aires, July, 1946), pp. 15-21; illus. In Spanish.

*"Petroleum Appraisal and Financing," by E. M. Reed. *Oil Weekly*, Vol. 123, No. 8 (Houston, October 21, 1946), pp. 57-61.

*"Secondary Recovery Research of the Bureau of Mines," by D. B. Taliaferro. *Independent Petrol. Assoc. Amer. Monthly*, Vol. 17, No. 6 (Tulsa, October, 1946), pp. 15-18; 4 photographs.

*"The Domestic Oil Producers Interest in Oil Shale," by Harry K. Savage. *Ibid.*, pp. 32-36; 2 tables, 1 graph, 1 photograph.

*"Possibilities and Problems of Drilling beyond the Continental Shelf," by Henry Emmett Gross. *Petrol. Engineer*, Vol. 18, No. 1 (Dallas, October, 1946), pp. 186-92; 6 figs. Probable locations of deposits are discussed, as well as a plausible method of drilling and its limitations.

*"Stratigraphical Problems in the Coal Measures of Europe and North America," by Arthur Elijah Trueman. *Quar. Jour. Geol. Soc. London*, Vol. 102, Pt. 2, No. 406 (London, July 31, 1946), pp. 49-93; 10 figs., 1 correlation chart, references. Anniversary address of the president of the Geological Society of London.

*"Volcanic Heat," by J. Verhoogen. *Amer. Jour. Sci.*, Vol. 244, No. 11 (New Haven, Connecticut, November, 1946), pp. 745-72.

Principes de géologie, by P. Fourmarier. 2d ed., revised and enlarged. 1212 pp. (2 vols.); 675 pls., figs. Published by Masson & Cie; H. Vaillant-Carmanne S. A. (Paris and Liége, 1944). Reviewed by Richard Foster Flint in *Amer. Jour. Sci.*, Vol. 244, No. 11 (New Haven, Connecticut, November, 1946).

*"Temperature Well Logging. Part 3, Temperature Distribution," by Hubert Guyod. *Oil Weekly*, Vol. 123, No. 10 (Houston, November 4, 1946), pp. 32-39; 17 figs.

**Ibid.* "Part 4, Wells in Thermal Equilibrium." Vol. 123, No. 11 (November 11, 1946), pp. 50–53; 8 figs.

*"Acidizing Increases Water Intake Rates," by R. J. Pfister. *Oil Weekly*, Vol. 123, No. 11 (Houston, November 11, 1946), pp. 70–74; 4 figs., 1 table.

*"Clay Research and Oil Development Problems," by J. C. Griffiths. *Ibid.*, pp. 82–89; 2 tables.

*"Oil Production by Water. Part 1, Basic Elements and Definitions," by Park J. Jones. *Oil and Gas Jour.*, Vol. 45, No. 26 (Tulsa, November 2, 1946), pp. 64–65.

**Ibid.* "Part 2, Dry-Oil Recovery for Uniform Distribution of Pay." Vol. 45, No. 27 (November 9), pp. 88–90; 4 figs.

**Ibid.* "Part 3. Oil Ahead of Water." Vol. 45, No. 28 (November 16), pp. 314–16; 6 figs.

*"A Review of Geophysical Methods, Devices, and Procedures," by C. H. Dresbach and Paul Weaver. *Oil and Gas Jour.*, Vol. 45, No. 26 (Tulsa, November 2, 1946), pp. 79–81.

"Oil and Gas Fields of the United States," by Paul Averitt, Jane Hanna, and Jane T. Carlton. *U. S. Geol. Survey* (November, 1946). 2 sheets, each 41 × 51 inches. Scale, approximately 1 inch equals 40 miles. Oil and gas fields developed to March 1, 1946, major refining centers, and major oil, gas, and petroleum products pipe lines. For sale by Director, Geological Survey, Washington 25, D. C.

GEORGIA

*"Geology and Ground-Water Resources of the Coastal Plain of East-Central Georgia," by Philip E. LaMoreaux. *Georgia Geol. Survey Bull. 52* (Atlanta, 1946). 173 pp., 2 pls., 21 figs.

ILLINOIS

*"Fresh- and Brackish-Water Vertebrate-Bearing Deposits of the Pennsylvanian of Illinois," by Everett Claire Olson. *Jour. Geol.*, Vol. 54, No. 5 (Chicago, September, 1946), pp. 281-305; 3 figs.

INDIANA

*"The Geology of Cataract Falls, Owen County, Indiana," by Clyde A. Malott. *Jour. Geol.*, Vol. 54, No. 5 (Chicago, September, 1946), pp. 322–26; 2 figs.

KANSAS

*"Geology and Ground-Water Resources of Grant, Haskell, and Stevens Counties, Kansas," by Thad G. McLaughlin. *State Geol. Survey Kansas Bull. 61* (Lawrence, July, 1946). 221 pp., 12 pls., 18 figs., 20 tables.

*"Glimpses from Resource-Full Kansas." 40-page, illustrated booklet published by the State Geol. Survey of Kansas, 1946. Contains brief stories about the scenery, mineral fuels, deposits of industrial minerals, rocks, fossils, and well-water supplies of Kansas.

MONTANA

*"Origin and Mechanics of the Thrust Faults Adjacent to the Bearpaw Mountains, Montana," by Frank Reeves. *Bull. Geol. Soc. America*, Vol. 57, No. 11 (New York, November, 1946), pp. 1033–48; 1 pl., 6 figs.

NEW JERSEY

*"Artificial Recharge of Productive Groundwater Aquifers in New Jersey," by Henry C. Barksdale and George D. DeBuchananne. *Econ. Geology*, Vol. 41, No. 7 (Urbana, Illinois, November, 1946), pp. 726–37; 3 figs.

NEW MEXICO

*"McCarty's Basalt Flow, Valencia County, New Mexico," by R. L. Nichols. *Bull. Geol. Soc. America*, Vol. 57, No. 11 (New York, November, 1946), pp. 1049–86; 8 pls., 15 figs.

OHIO

'Map of the Berea Sand of Northern Ohio," by J. F. Pepper, D. F. Demarest, W. De-Witt, Jr., R. D. Holt, and C. W. Merrels 2d. *U. S. Geol. Survey Prelim. Map 39*, Oil and Gas Investig. Ser. (October, 1946). Map on Sheet 1 covers 8,000 square miles, and shows productive oil and gas pools. Sheet 2 includes maps, diagrams, cross sections, and text describing Berea sand. For sale by Director, Geological Survey, Washington 25, D. C. Price, $0.65.

PACIFIC REGION

*"Drowned Ancient Islands of the Pacific Basin," by H. H. Hess. *Amer. Jour. Sci.*, Vol. 244, No. 11 (New Haven, Connecticut, November, 1946), pp. 772–92; 8 figs.

*"Lithification of Pleistocene Clay at Kahuku Point, Oahu," by Randolph W. Chapman. *Bull. Geol. Soc. America*, Vol. 57, No. 11 (New York, November, 1946), pp. 985–96; 2 pls., 2 figs.

SOUTH AMERICA

*"Reservas Petroliferas de Sud America" (Petroleum Reserves of South America), by Victor Oppenheim. *Boletin de Minas y Petroleo*, Vol. 16, No. 9 (Mexico, D. F., September, 1946), pp. 43–44. Taken from *Boletín del Instituto Sudamericano de Petróleo*, Montevideo, Uruguay. In Spanish.

TEXAS

*"West Texas Modern Refraction Seismic Exploration," by Sidon Harris. *Oil Weekly*, Vol. 123, No. 7 (Houston, October 14, 1946), pp. 52–55; 4 figs. Modern techniques being used on the Edwards Plateau area of West Texas.

*"South Texas Giant," by Charles J. Deegan and Neil Williams. *Oil and Gas Jour.*, Vol. 45, No. 27 (Tulsa, November 9, 1946), pp. 60–64; 5 figs, including type electrical logs and subsurface structural map of line of oil fields along Vicksburg flexure in South Texas.

WEST INDIES, MEXICO, CENTRAL AND SOUTH AMERICA

"Magnetic Observations in the American Republics, 1941–44," *U. S. Coast and Geodetic Survey Serial 677* (October, 1946). Report prepared in cooperation with U. S. Department of State and governments of various American Republics. Illustrations include maps showing distribution of stations, diagrams of daily variation curves, and reproductions of photographs showing personnel, instrumental equipment, observations, and station sites. For sale by Superintendent of Documents, Government Printing Office, Washington 25, D. C. Price, $1.25.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 12 (DECEMBER, 1946), PP. 2071-2092

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REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL: PHILIP B. KING (1949)

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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REGIONAL MEETING, BILOXI, MISSISSIPPI, OCTOBER 24-25, 1946[1]

GORDON I. ATWATER[2]
New Orleans, Louisiana

The mid-year meeting of the A.A.P.G. was held at the Buena Vista Hotel, Biloxi, on the Mississippi Gulf Coast. The Mississippi Geological Society sponsored the meeting, and the officers and committees that arranged and conducted the program can indeed be complimented on its success.

Registrations totaled 477 members and 110 guests, including a good representation of wives. Earl Noble, president of the A.A.P.G., D. Perry Olcott, vice-president, Edward A. Koester, secretary-treasurer, Gayle Scott, editor, and Monroe G. Cheney, past-president, were present. Hotel accommodations were excellent, and the inconvenience of those not registered in the headquarters hotel was more than offset by the beauty of the coast along which the other hotels were located. Our hosts had every reason to be proud of the delightful winter Gulf Coast weather that lasted throughout the meeting.

[1] Manuscript received, November 20, 1946.

[2] Consulting geologist, 1034 Whitney Building.

The technical program was devoted to the geologic features of the southeastern states. It was well balanced between regional studies and summaries, and detailed reports on a number of the characteristic fields. Sufficient time was given each speaker to present his paper in detail, and the meetings benefited by emphasis on fewer papers, well and fully presented. There was a lack of general discussion, however, following the papers which might well be encouraged at mid-year meetings where time is less of a premium. If necessary, discussions could in part be planned in advance.

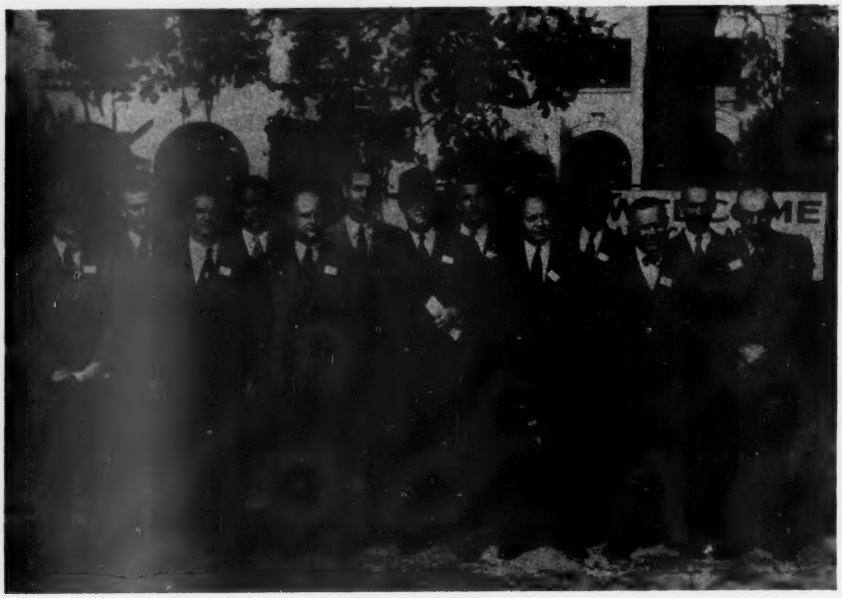

FIG. 1.—MISSISSIPPI GEOLOGICAL SOCIETY CONVENTION HEADS AND ASSOCIATION OFFICERS, BILOXI REGIONAL MEETING.

Left to right: CARL F. GRUBB, HARRY H. EMMERICH, JOE B. WHEELER, J. B. STOREY, H. L. SPYRES, M. E. NORMAN, E. B. NOBLE (president, A.A.P.G.), F. F. MELLEN, R. M. HARRIS, PERRY OLCOTT (vice-president, A.A.P.G.), GAYLE SCOTT (editor, A.A.P.G.), C. W. ALEXANDER, B. W. ALLEN.

General comment appeared to be in favor of the Association encouraging mid-year meetings of this type for the presentation of technical papers dealing with restricted areas, where the majority of those present will be interested in practically every paper. As the Association grows, it is possible that the emphasis of annual meetings should be on business, with the technical program restricted to problems of nation-wide interest, while mid-year meetings be systematically developed into symposiums devoted to technical papers on specific areas or regions.

The program of the Biloxi meeting follows.[3]

[3] Abstracts of the Biloxi meeting papers were published in the November *Bulletin*, pp. 1963–68.

FIG. 2.—BANQUET GROUP AT BILOXI MEETING.

Left to right: E. A. MARKLEY, MRS. R. E. SHUTT, STEFAN VON CROY, MRS. ROBERT MORTON, ROBERT MORTON, R. E. SHUTT, MRS. C. N. VALERIUS, C. N. VALERIUS, MRS. R. J. RIGGS, R. J. RIGGS.

FIG. 3.—BUENA VISTA HOTEL, BILOXI MEETING HEADQUARTERS.

October 24

Presiding in Forenoon, J. B. Storey

Address of Welcome, Alexander McKeigney, executive-secretary to the Governor of Mississippi

Response, F. F. Mellen, president of the Mississippi Geological Society

Response, Earl B. Noble, president of the American Association of Petroleum Geologists

Introductory Remarks relative to the conduct of the technical sessions and entertainment, J. B. Storey

Historical Notes on the Geology of Mississippi, Urban B. Hughes, consulting geologist, Laurel, Mississippi

Stratigraphy and Petroleum Geology of Black Warrior Basin, Mississippi and Alabama, Frederic F. Mellen, Mellen & Monsour, Jackson, Mississippi

Surface Occurrence of Cretaceous Beds in the Southeastern States, Watson H. Monroe, United States Department of the Interior, Geological Survey, Washington, D. C.

Subsurface Occurrence of Cretaceous Sediments of Mississippi, C. W. Alexander, Dixie Geological Service; R. M. Harris, Harris & Payne, Jackson, Mississippi

Presiding in Afternoon, K. K. Spooner

Cenozoic Deposits of Mississippi and Adjacent Areas, Grover Murray, Jr., Magnolia Petroleum Company, Jackson, Mississippi

Status of Micropaleontology in the Eastern Gulf Region, Henry V. Howe, Louisiana State University, Baton Rouge, Louisiana

General Geology and Occurrence of Oil in Florida, E. D. Pressler, Humble Oil and Refining Company, Tampa, Florida

Banquet—Henry Toler, toastmaster, Rose Room, Buena Vista Hotel

President Earl B. Noble discussed Association affairs. Elmer W. Ellsworth, assistant business manager of the A.A.P.G. talked informally on the growth of the business handled by our main office through the years of expansion of the society. The dance on the Deck of the Buena Vista Hotel, following the banquet, was well attended.

October 25

Presiding in Forenoon, M. L. Kerlin

Subsurface Correlations of East Texas, North Louisiana, South Arkansas, and Mississippi, Roy T. Hazzard, Gulf Refining Company, Shreveport, Louisiana

Formation of Evaporites under Marine Evaporation Conditions, Paul Weaver, Gulf Oil Corporation, Houston, Texas

Mesozoic Igneous Rocks of the Northern Gulf Coastal Plain, C. L. Moody, The Ohio Oil Company, Shreveport, Louisiana

Geology of the West Tepetate Oil Field, Jeff Davis Parish, Louisiana, Fred W. Bates and Jay B. Wharton, consulting geologists, Lafayette, Louisiana

Presiding in Afternoon, U. B. Hughes

The Delhi, West Delhi, and Big Creek Fields, Richland, Madison and Franklin Parishes, Louisiana, A. M. Lloyd, Sun Oil Company, Dallas, Texas; R. B. Totten, Sun Oil Company, Monroe, Louisiana

Geology of the Gilbertown Field, Choctaw County, Alabama, A. M. Current, Carter Oil Company, Jackson, Mississippi

The Tinsley Field, F. R. Schroeder, Union Producing Company, Shreveport, Louisiana; J. B. Storey, Union Producing Company, Jackson, Mississippi

The Cranfield Field, Adams and Franklin Counties, Mississippi, George P. Zebal, The California Company, Natchez, Mississippi

The Heidelberg Field, Jasper County, Mississippi, Tom McGlothlin, Gulf Refining Company, Laurel, Mississippi

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MID-CONTINENT REGIONAL MEETING, WICHITA, KANSAS, JANUARY 16–17, 1947

A regional meeting of the American Association of Petroleum Geologists, sponsored by the Kansas Geological Society, will be held at Wichita, Kansas, with the Broadview Hotel as headquarters. Papers cover unusual fields and future of Mid-Continent.

The Broadview Hotel can not accommodate the entire attendance anticipated, but all requests for reservations should be addressed directly to the Broadview Hotel, which

will handle transfers of reservations to the Allis, Lassen, and other Wichita hotels. Each of these is located within one-half mile radius of the headquarters hotel.

It is imperative that the committee know, as near as possible, how many will attend; accordingly, please return promptly the card that has been mailed you, indicating the possibility of your attendance.

Registrations will begin at noon, Wednesday, January 15. The research committee will meet all day Wednesday. The geologic names and correlations committee also meets. An informal Open House will be held in the Bamboo Room of the Broadview, at 8 P.M., January 15.

On January 16, there are meetings of the distinguished lecture committee and the committee on applications of geology.

On the night of January 16, a dance is planned, and entertainment for the ladies is also planned for the afternoon of January 17.

Some of the papers scheduled for presentation at this meeting are here listed.

1. Unusual Oil Fields of the Rocky Mountain Province, by C. E. Dobbin
2. Norman Wells Oil Field, Canada, by J. S. Stewart
3. Deep River Pool, Michigan, by K. K. Landes
4. Adams Pool, Michigan, by Rex P. Grant
5. Pools of Geneseo Trend, Kansas, by Stuart K. Clark
6. Marine Pool, Madison County, by H. A. Lowenstam
7. Hugoton Gas Field, Kansas, by L. C. Morgan *et al.*
8. Rangely Oil Field, by J. M. Kirby *et al.*
9. Antioch Pool, Garvin County, Oklahoma, by Lon B. Turk
10. West Edmond Field, Oklahoma, by Robert M. Swesnik
11. Kraft-Prusa Field, Kansas, by R. F. Walters
12. Moren-Kisinger Pool, North-Central Texas, by M. G. Cheney
13. Geophysical Case History of Guthrie Field, Oklahoma, by B. G. Swan and W. Baxter Boyd. (Sponsored by Society of Exploration Geophysicists.)

1. Structural Framework of the Mid-Continent Region, by Ira H. Cram
2. Anadarko Basin and Its Oil Possibilities, by Robert R. Wheeler
3. Oil Possibilities of the Las Animas Arch, by Harry W. Oborne
4. Subdivisions of the Arbuckle Dolomite in Western Kansas, by Joseph R. Clair
5. Role of Geophysics in Future Development of Mid-Continent, by Gerald H. Westby
6. Radioactivity Well Logging, by V. J. Mercier
7. Detailed Core of Hunton Limestone in West Edmond Field, by J. T. Richards

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FUNCTIONS AND ORGANIZATION OF GEOLOGIC NAMES AND CORRELATIONS COMMITTEE[1]

HENRY J. MORGAN, JR.[2]
Dallas, Texas

It is the desire and aim of the geologic names and correlations committee to enlist the aid of the affiliated societies, sections, and local groups in large-scale cooperative projects having to do with the nomenclature and correlation of formations located in the areas of interest to them.

Since the interest of the cooperating groups lies in areas which, geographically, cover a sizeable part of the United States and a part of Canada and, geologically, include the entire geologic section, it is at once apparent that the organization must be large and it must be able to function simultaneously in all parts of the country and in all parts of the section.

[1] Manuscript received, October 7, 1946.

[2] Chairman of the committee. Atlantic Oil and Refining Company.

It is equally apparent that the task would be a full-time job for a number of competent geologists if they intended to perform it alone. However, if a method can be devised to tap systematically the mass knowledge of the 31 local groups and, if this method can break the work into small enough parts so that each society performs only a small part of a large project, then it is believed that the organization outlined in Table I can realize its aim.

In this organization outline, the geologic column is divided into three parts: Cenozoic, Mesozoic, and Paleozoic. The country is divided into geographical areas that include the best development of beds of Cenozoic, Mesozoic, and Paleozoic ages.

TABLE I

ORGANIZATION CHART OF GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

President and Executive Committee of A.A.P.G.

- Geologic Names and Correlations Committee
  - Cenozoic Sub-Committee
    - District Committee Study Groups
      - Western Gulf Coast
        1. South Texas Section of A.A.P.G.
        2. Corpus Christi Geological Society
        3. Houston Geological Society
        4. South Louisiana Geological Society
        5. New Orleans Geological Society
        6. East Texas Geological Society
        7. Shreveport Geological Society
      - Eastern Gulf Coast
        1. Mississippi Geological Society
        2. Southeastern Geological Society
        3. New Orleans Geological Society
      - Atlantic Coast
        1. Southeastern Geological Society
        2. Eastern Section of A.A.P.G.
      - Rocky Mountains and Great Plains
        1. Rocky Mountain Association of Petroleum Geologists
        2. Wyoming Society of Petroleum Geologists
        3. Alberta Society of Petroleum Geologists
        4. Yellowstone-Bighorn Research Association
      - Pacific Coast
        1. Pacific Section of A.A.P.G.
        2. San Joaquin Valley Geological Society
  - Mesozoic Sub-Committee
    - District Committee Study Groups
      - Gulf Coast
        1. South Texas Section of A.A.P.G.
        2. Fort Worth Geological Society
        3. Dallas Geological Society
        4. East Texas Geological Society
        5. Shreveport Geological Society
        6. Mississippi Geological Society
        7. Southeastern Geological Society
      - Atlantic Coast
        1. Southeastern Geological Society
        2. Eastern Section of A.A.P.G.
      - Rocky Mountains and Great Plains
        1. Rocky Mountain Association of Petroleum Geologists
        2. Wyoming Geological Association
        3. Alberta Society of Petroleum Geologists
        4. Yellowstone-Bighorn Research Association
      - Pacific Coast
        1. Pacific Section
        2. San Joaquin Valley Geological Society

Paleozoic Sub-Committee
- District Committee Study Groups
  - Rocky Mountains and Great Plains
    1. Rocky Mountain Association of Petroleum Geologists
    2. Wyoming Geological Association
    3. Yellowstone-Bighorn Research Association
    4. Alberta Society of Petroleum Geologists
  - Mid-Continent
    1. Mississippi Geological Society
    2. Oklahoma City Geological Society
    3. Shawnee Geological Society
    4. Tulsa Geological Society
    5. Kansas Geological Society
  - Eastern Interior
    1. Indiana-Kentucky Geological Society
    2. Illinois Geological Society
    3. Michigan Geological Society
    4. Mississippi Geological Society
  - Southwestern United States
    1. West Texas Geological Society
    2. Panhandle Geological Society
    3. North Texas Geological Society
    4. Fort Worth Geological Society
    5. Ardmore Geological Society
    6. Dallas Geological Society
    7. South Texas Section of A.A.P.G.
  - Appalachian Region
    1. Appalachian Geological Society
    2. Eastern Section of A.A.P.G.
    3. Pittsburgh Geological Society

Advisory and Special Projects Sub-Committee
- Temporary Committees

Each of the three main geologic divisions is covered by a chairman and a sub-committee. The members of each sub-committee are co-chairmen of geographical districts which contain well developed beds of the age in question.

The district co-chairmen, in turn, have committees whose membership is drawn from the local societies in their districts. They can have as many men on their committee as they wish, but each local society or other group should be represented on these district committees.

Each society in each district will be asked to appoint a study group to cooperate upon some project whose importance is mutually agreed on. The geologic names and correlations committee representative in each society should be a member of the study group, but should not necessarily be its chairman.

The outline contemplates, also, the formation of an advisory committee whose members will act as consultants on matters submitted to them and will handle special projects turned over to the main committee by the Association executive committee. This committee will have rank equal to that of the other sub-committees.

Since many of the projects will involve the making of cross sections and correlation charts, portions of which will be divided among the societies along the route, it is planned for each society to submit its part for publication, together with text giving its reasons for correlations, as soon as completed.

NOMINEES FOR OFFICERS, 1947-1948

For President

C. E. Dobbin

John G. Bartram

C. E. Dobbin, Regional Geologist, United States Geological Survey, Denver, Colorado
Born, West Jonesport, Maine, October 2, 1892

Academic Training

Colby College	Geology A.B., 1916
Colby College	Honorary Ph.D., 1941
Johns Hopkins University	Geology Ph.D., 1924

Experience
U. S. Geological Survey 1918–

Publications—Field of structural geology, and geology of oil, gas, and coal

Professional Affiliation (National)
American Association for the Advancement of Science
American Geophysical Union
American Institute of Mining and Metallurgical Engineers
American Society of Photogrammetry
Geological Society of America

A.A.P.G. Activity

1932	Constitution and By-Laws Committee
1932–1938	Research Committee
1932–1936; 1939–1941	Business Committee
1933–1935	Associate Editor
1936	Vice-President
1939	Committee on Methods of Electing Officers
1939, 1943–1945	(vice-chm); 1945 (chm): Committee for Publication
1939–1942	Committee on Applications of Geology (chm, 1939–1941)
1943–1944	Geologic Names and Correlations Committee, Sub-Committee on Mesozoic
1946	Representative on Council of American Association for the Advancement of Science

JOHN G. BARTRAM, Assistant Manager of Exploration, Stanolind Oil and Gas Company, Tulsa, Oklahoma
Born, Lakeville, Connecticut, November 27, 1893
Academic Training

Williams College, 1910–1914	Chemistry B.A., 1914
Williams College, 1914–1915	Geology Graduate Work
Johns Hopkins University, 1915–1916	Geology Graduate Work

Experience

Roxana Petroleum Corporation	1916–1923
Midwest Refining Company	1923–1932
Stanolind Oil and Gas Company	1932–

Military Service—Ordnance, 1918–1919
Publications—Field of petroleum geology
Professional Affiliation (National)
Geological Society of America
A.A.P.G. Activity

1933–1945; 1937–1945 (chm)	Geologic Names and Correlations Committee
1936–1938	Research Committee
1942–1946; 1944 (chm)	Representative on Commission on Classification and Nomenclature of Rock Units
1944–1945 (chm)	Committee on Method of Election of Officers

FOR VICE-PRESIDENT

GEORGE S. BUCHANAN

GEORGE S. BUCHANAN, Manager, Gulf Coast Division, Sohio Petroleum Company, Houston, Texas
Born, Sterling, Colorado, September 1, 1902
Academic Training

University of Michigan, 1920–1922	Geology A.B., 1922
University of Michigan, 1923–1924	Geology M.S., 1924

Experience

Pure Oil Company	1924–1925
Carter Oil Company	1925–1928
Tulsa Oil Company	1928–1932
Barnsdall Oil Company	1932–1933
Adams Louisiana Company	1934–1939
Yegua Corporation	1940–1944
Sohio Petroleum Company	1945–

Military Service—Infantry, 1918
Publications—Field of petroleum geology
A.A.P.G. Activity

1939–1940	Trustee of Revolving Publication Fund
1940	Committee to Recommend a New Way of Electing Officers
1940	Committee on Mimeographed Publications
1942–1943	Committee on Applications of Geology
1945–1946	Business Committee (chm, 1945)

FOR SECRETARY-TREASURER

J. V. HOWELL

J. V. HOWELL, Consultant, Tulsa, Oklahoma
Born, Oskaloosa, Iowa, March 11, 1891
Academic Training

Penn College (Iowa), 1908–1912	Chemistry B.S., 1912
University of Iowa, 1913–1916	Geology M.S., 1916
University of Iowa	Geology Ph.D., 1921

Experience

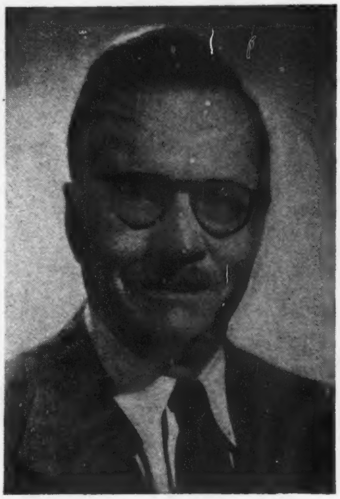
The Texas Company	1916–1918
Gypsy Oil Company	1918–1921
University of Iowa, Instructor in geology	1921–1922
Marland Oil Company	1922–1929
Consulting Geologist, Tulsa, Oklahoma	1929–

Military Service—Field Artillery, 1918
Publications—Field of structural, economic, and petroleum geology
Professional Affiliation (National)
Geological Society of America

A.A.P.G. Activity

1927; 1939	Business Committee
1930	Committee on Method of Election of Officers
1936–1938	Trustee of Revolving Publication Fund
1940	Committee for Recommending a New Way for Electing Officers
1942–1944	Chairman, Committee for Publication
1945	Vice-Chairman, Committee for Publication
1946	Editor of Volume III, *Structure of Typical American Oil Fields*

For Editor



C. L. Moody

C. L. Moody, Division Geologist, The Ohio Oil Company, Shreveport Louisiana
Born, Compton, California, October 26, 1888

Academic Training

University of Southern California	1909–1910	
University of California	1912–1916	Geology A.B., 1916
University of California	1917	Geology Graduate Student

Experience

Consulting Geologist, Casper, Wyoming, 1917–1918
The Ohio Oil Company, 1918–

Publications—Field of stratigraphy and structure of Rocky Mountain and Gulf Coast areas

Professional Affiliation

American Association for the Advancement of Science
Geological Society of America

A.A.P.G. Activity

1932–1940	Geologic Names and Correlations Committee
1933–1938	Associate Editor
1937	Vice-President
1937; 1939–1941; 1946 (vice-chm, chm)	Business Committee
1943–1945; 1945 (chm)	Trustee of Research Fund
1943–1944	National Service Committee
1945	Committee on Statistics of Exploratory Drilling
1945	Committee on Method of Election of Officers

Pacific Section annual meeting luncheon in Embassy Room, Ambassador Hotel, November 7.

PACIFIC SECTION ANNUAL MEETING, LOS ANGELES, CALIFORNIA, NOVEMBER 7-8, 1946

The Pacific Section of the Association held its annual meeting, November 7 and 8 at the Ambassador Hotel, Los Angeles. Concurrently meeting with the A.A.P.G. were the Pacific Section of the Society of Economic Paleontologists and Mineralogists and the Pacific Coast District of the Society of Exploration Geophysicists.

The officers of the A.A.P.G. Pacific Section whose terms ended with this meeting are: E. R. Atwill, president; V. W. Vandiver, vice-president; and A. S. Holston, secretary-treasurer. The program committee was composed of J. R. Dorrance, chairman, Wayne Loel and J. E. Matter. The arrangements committee was Frank Carter, chairman; Lloyd Metzner, and Harold Rader. Publicity was handled by Gordon Bell.

Incoming officers elected at this meeting are: president, Martin Van Couvering, consultant; vice-president, W. P. Winham, Standard Oil Company of California; and secretary-treasurer, Clifton Johnson, Richfield Oil Corporation.

The registration of geologists, geophysicists, paleontologists, and friends numbered 450. About 200 attended the joint luncheon of the 3 groups at noon the first day, when committeemen and guests were introduced by toastmaster Atwill, and national A.A.P.G. president E. B. Noble discussed research problems of the Association and gave a digest of the papers presented at the Biloxi, Mississippi, regional meeting, which was held on October 24 and 25. Representing the national headquarters staff at Tulsa, Oklahoma, assistant business manager E. W. Ellsworth and business manager J. P. D. Hull made brief remarks. A special feature of the luncheon ceremony was the presentation of a wrist watch to Martin Van Couvering as a token of esteem from the members of the Pacific Section Geological Forum, of which he is chairman.

The annual dinner dance of the Section was the social event of the meeting, held in the Embassy Room of the Ambassador Hotel on Friday evening, November 8.

The following are the titles and abstracts of the papers on the technical program of the Section, including those of the S.E.P.M.

PACIFIC SECTION ABSTRACTS

1. "Notes on the Stratigraphy of the Santa Maria District," Aden W. Hughes, Union Oil Company, Santa Maria.

Seven oil fields in the Santa Maria District produce oil from four different formations. The most prolific of these is the Monterey shale (middle and upper Miocene). Oil in the Knoxville sandstone, discovered in 1943, created a mild drilling boom, but was limited in areal extent. Lospe production is the latest economic interest in the district. Variation in the age of the Monterey cherty shale in the Santa Maria Valley and other fields makes correlations difficult. Ditch sampling of development as well as wildcat wells has been a valuable practice in stratigraphic control and aid in electrolog correlations. Microscopic study of washed samples shows definite lithologic changes that carry over wide areas.

2. "The Ostracoda in Paleogeography," W. T. Rothwell, Jr., Richfield Oil Company, Long Beach

A study of the depth-distribution of recent ostracods in the San Pedro Channel from Long Beach to Avalon Bay, Catalina Island, has revealed a new tool to aid in the solution of paleogeographic and ecologic problems in California stratigraphy. These microscopic crustaceans are very abundant in shallow salt-water lagoons, in mainland continental shelf sediments down to a water depth of 500 feet, and along protected island shores. The samples collected by Alex Clark and Manley L. Natland show by the presence of soft parts that the more abundant species of ostracods were alive on the bottom when dredged.

Comparison with the 26 fossil forms recorded by L. W. LeRoy in 1944 reveals eighteen of his species and varieties surviving to Recent time. Total recent forms recognized to date number approximately 22 genera, 52 species, and 7 subspecies.

The following geologic formations and Recent ostracod habitats are grouped together to suggest similar environments, as inferred from the occurrence in each of certain characteristic genera and species.

I. Lower San Joaquin Formation (Upper Pliocene) and Salton Sea deposits (Recent?)
II. Upper Etchegoin Formation (Pliocene) and Sunset Lagoon (Recent), Salt marshes of Mission Bay (Recent)
III. Upper Imperial Formation (Pliocene) and shore waters of the Gulf of California (Recent), mouth of Mission Bay (Recent)
IV. Upper Pico Formation (upper Pliocene or Pleistocene), Lower Etchegoin Formation (Pliocene), lower Imperial Formation (Pliocene or Miocene), Upper Wildcat Series (Upper Pliocene) and Pacific Coast, exposed, continental shelf bottom deposits
V. Lomita marl (Lower Pleistocene or Upper Pliocene) and Catalina Island lee shore marl (Recent)

Slides are presented to show locality map, anatomy, representative species, and occurrences in the Pliocene of the Midway-Sunset oil field, Kern County, California.

3. "The Glendora Volcanics," JOHN S. SHELTON, Pomona College, Claremont.

The term Glendora volcanics has been given to the series of volcanic rocks exposed in the northeastern San Gabriel basin, Los Angeles County, California. They consist of flows, tuff breccias, and tuffs ranging in composition from olivine basalt to glassy rhyolite or dacite, the most abundant being andesitic flows and pyroclastics. Thicknesses reach at least 2,000 feet in exposed sections and about 3,500 feet in wells. Luisian Foraminifera and fish scales from sediments interbedded with upper members of the volcanics indicate that they are probably largely of upper middle Miocene age.

4. "Highlights of Washington and Oregon Biostratigraphy," R. STANLEY BECK, consulting paleontologist, Bakersfield.

The biostratigraphy of type and classical localities of Washington and Oregon is discussed. Special emphasis is given to the Astoria, Cowlitz, Olympic peninsula and Coos Bay basins. Strata from Devonian to Recent are known from these areas and have a combined thickness of over 30,000 feet. These basins, as well as others, are possible areas in which oil and gas might be discovered in the future. Favorable as well as unfavorable geologic conditions will be discussed concerning oil possibilities of the Pacific Northwest.

5. "Tidal Waves from the Recent Aleutian Earthquake," FRANCIS P. SHEPARD, Scripps Institution of Oceanography, La Jolla.

On April 1, 1946, a sudden movement of the ocean bottom in the Aleutian deep started a train of sea waves which were picked up on tide gauges as far away as Australia and South America. Great damage was done to all of the north coasts of the Hawaiian Islands and the waves surged to heights as great as 55 feet in some places of convergence. Investigation of the five main Hawaiian islands showed relationships between high water marks and submarine topography. Also the height was greatly influenced by the existence of coral reefs and lagoons along the shore. Investigations in Hawaii have been compared with determinations by the Japanese in the 1933 tidal waves to devise a means of forecasting the relative danger of different situations from future tidal waves.

Personal experiences during the tidal wave are given along with accounts of other observers.

6. "Effects of World War II on California Oil Reserves," Graham B. Moody, Standard Oil Company of California, San Francisco.

The enormous demands of World War II for California oil were met successfully. Production was increased from 230,263,000 barrels in 1941 to 326,555,000 barrels in 1945. This is an increase of 41.8%. The comparable figure for the balance of the United States is 18%. During the period 1941 to 1945, inclusive, California produced 18.2% of total United States oil production and 11.7% of total world production. It increased its proportion of total United States production from 16.4% in 1941 to 19.1% in 1945. One other record of past performance is of interest: California had produced to December 31, 1945, about 22% and 14% of total cumulative production from the United States and the world, respectively. This performance was accomplished by development of about 245,000 proved productive acres, a small area compared to that in other producing states. Average ultimate recovery from California fields is estimated to be about 44,000 barrels per acre. Other major producing states have estimated ultimate recoveries of 8,000 to 14,000 barrels per acre. California pools have sufficient thickness to compensate for their restricted areal extent.

Despite the drain on California's oil resources by World War II, production in the middle of September, 1946, was about 870,000 barrels daily; the daily average during 1941 was about 631,000 barrels. During the period 1941 to 1945, inclusive, the discovery of new pools and new fields in California added estimated reserves equal to about one-third of production during that period. Additional reserves must be discovered in order to continue to meet the unprecedented peacetime demand for California oil. More new pools in present producing areas probably will add larger amounts to reserves than will new fields (Tidelands excepted). It will require intensified geological effort to find

these new reserves. There still is ample opportunity in California for the competent and imaginative geologist who can evolve a productive program from a mass of factual information.

7. "Time of Oil and Gas Accumulation, A. I. LEVORSEN, Stanford University.

A perplexing problem in petroleum geology is whether the oil and gas originate at or very near the point of accumulation, or whether they have migrated in from some distant area of origin. Examples of both *in situ* and distant origin can be cited that seem to indicate both occur in nature.

For those pools which seem to indicate migration from a distant source, a rough guide as to the time of the accumulation is offered. It is based on the timing of the formation of the trap into which the oil and gas accumulate—the accumulation cannot occur before the trap is formed. In considering the interval between the time of formation of the reservoir rock and the present time, most producing traps can be separated into the varying component elements which go to make up the trap as it now exists. Examples of different combinations of trapmaking events are given as a guide to the time before which accumulation could not have occurred. Furthermore, the capacity of a trap is in part a function of the depth of burial of the reservoir—a phenomenon which also supports a relatively late accumulation of many pools.

8. "Permafrost and Related Engineering Problems," SIEMON WM. MULLER, Stanford University.

Permafrost or permanently frozen ground is a widespread phenomenon in the northern hemisphere. About one-fifth of all land area of the world is underlain by permafrost.

Wherever present, permafrost affects in one way or another (or is itself affected by) every field of human endeavor. The consideration of permafrost is vital in planning transportation routes, settlements, pipelines, drilling operations, etc. Roads, railroads, and buildings, inappropriately located or improperly designed and built, are likely to be damaged and rendered useless. Drilling tools may freeze in the hole, causing the abandonment of a project. In the permafrost area, the problem of water supply claims foremost attention.

Stresses that develop in freezing ground may exceed 2,000 kilograms per square centimeter. Just as the Russians have done in the past, we are learning, in the hard way, that it is uneconomical if not futile to "fight" the natural forces of frost by using stronger materials, more rigid designs, or to resort to periodic and costly repairs, which rarely if ever succeed in a permanent righting of the situation. Successful solution of permafrost problems depends on a thorough understanding and correct quantitative evaluation of the component elements and on the planning of the project in such a way that the frost forces are utilized to play into the hand of the engineer and not against it. A thorough and comprehensive survey of the permafrost conditions should therefore constitute a preliminary and an integral part of any engineering project.

9. "The Cretaceous of Colombia," J. WYATT DURHAM, California Institute of Technology, Pasadena.

During the Cretaceous varying amounts of marine and non-marine sediments were deposited in the North Andean geosyncline which passed through Venezuela, Colombia, and Ecuador. During the maximum period of flooding, all except extreme Western Colombia, part of Eastern Colombia, and a few islands appear to have been covered by the seaway. The Cretaceous sediments usually begin with a sandstone or limestone, which is followed by a thick sequence of black shales with occasional limestone members. Following the black shales, there is a more or less cherty shale or limestone, which is followed by either sands and shales or shales and limestones. The thickness of the sediments varies from around 2,000 feet to more than 40,000 feet. Marine faunas are often abundant and show marked relationships to both the Gulf Coast and the European Cretaceous faunas. From the faunas collected at various localities it appears that most, if not all of the standard Cretaceous section is represented in Colombia.

10. "Origin and Migration of Oil into Sespe Red Beds," THOMAS L. BAILEY, Rothschild Oil Company, Santa Fe Springs.

The name "Sespe formation" is applied to the non-marine red bed facies of a group of sedimentary rocks up to 7,500 feet thick. They range in age from upper Eocene into lower Miocene in the southern and eastern part of the Ventura basin but are probably confined to the Oligocene in most of the northwestern part of that basin. The lower portion becomes progressively marine westward beginning about 25 miles west of Santa Barbara, however, this marine Oligocene is mainly sandstone, low in organic material, and can hardly be a source rock.

The bulk of the evidence suggests that most of the oil was derived from Eocene shales. Upward migration across the bedding of several hundred to a few thousand feet of predominantly sandy strata seems to be required. Countless minor joints and cracks in the shaly interbeds are suggested as the principal channels of upward migration. In the southeastern part of the Ventura basin, some of the oil may have reached the lower, or Eocene portion of the Sespe by lateral migration from upper Eocene shales into which the lower Sespe may grade, followed by upward migration within the anticlines to the shalier middle Sespe where it is trapped.

11. "Evidence Supporting Lateral Migration of Oil, San Joaquin Valley, California," GLENN C. FERGUSON, consulting paleontologist, Bakersfield.

Considerable evidence has been presented from time to time in various geologic publications favoring the accumulation of oil derived from "local rich accumulations of organic matter deposited in restricted areas near to, indigenous to, or in contact with the reservoir and trap." Opposed to this view, other authors have favored substantial migration, either lateral or vertical, or both.

Evidence is presented strongly supporting, if not conclusively proving that oil, when provided the proper avenue for underground movement, does migrate laterally over distances of several miles. Nothing is implied to indicate that oil may not have accumulated locally, having been derived from restricted areas, underground stratigraphic, and structural conditions being the governing factors at all times.

12. "Accumulation of Oil in Continental Sediments at the South Belridge Oil Field, Kern County, California," E. J. COENEN and H. D. HOBSON, General Petroleum Corporation, Bakersfield.

Factual data are presented concerning the accumulation of oil in continental sediments at the South Belridge oil field. Included are the structure and stratigraphy of the field, the reservoir characteristics of the sediment and the properties and distribution of the oil and associated waters. The lithology, organic content, and included fluids of adjacent marine sediments are discussed with the objective of making tentative suggestions as to the origin, migration, and accumulation of the oil.

13. "Petroleum on the Continental Shelves," WALLACE PRATT, American Association of Petroleum Geologists Distinguished Lecturer, Frijole, Culberson County, Texas.

President Truman's executive proclamation of September 25, 1945, declaring the continental shelf contiguous to our coasts to be subject to our jurisdiction and control, fell upon the ears of a petroleum industry which in its worldwide search for new sources of supply, had already found its exploratory operations on more than one continent brought to a stop at the land's edge across which it had for years peered uncertainly out to sea. The problem of petroleum resources on the continental shelf challenges first the geologist, then the engineer. The geologist's immediate and pressing responsibility is to review his accumulated knowledge of the character of the continental shelf, and in the light of his concepts of the origin and occurrence of petroleum, to measure the adequacy of the reward which awaits the conquest of petroleum under the submerged margins of the continents to compensate the risk, effort, and expense which this task poses for the engineer. In reply to this challenge to geologists, it is submitted that if the earth is viewed as a functioning organism, surely one of its normal functions since life covered its surface has been the generation of petroleum, much greater volumes of petroleum than are now believed to exist beneath the land areas of the earth should have been formed through the ages. The most likely place to search for these possible additional stores of petroleum is the continental shelf.

14. "Geology of Basement Complex, Edison Oil Field, Kern County, California," J. H. BEACH, Independent Exploration Company, Bakersfield, and HARRY CAMPBELL, Jergins Oil Company, Bakersfield.

The pre-Tertiary metamorphics in the Edison oil field have, since the discovery of this zone by H. H. Magee in June, 1945, yielded 3,330,000 barrels of oil to August 31, 1946. Of the one hundred and three wells which have since been drilled into the basement during its development, all but six have been completed as commercial producers.

Oil has accumulated within the metamorphics in approximately the same area that contains oil in the overlying sediments. The oil produced from the basement is similar to that of the oil produced from the sands, although gravities vary greatly.

Wells with highest initial potentials and highest productivity indices are those completed in the hard, fresh fractured rocks on locally developed structural highs on the Edison uplift.

15. "Santiago Pool, Kern County, California," GLENN W. LEDINGHAM, Western Gulf Oil Company, Bakersfield.

The Santiago pool is located in Secs. 21 and 22, T. 11 N., R. 23 W., in the south San Joaquin Valley. The initial completion was on August 1, 1945, and since that time 26 producers and 4 dry holes have been drilled.

Production was established from an upper Miocene sand roughly equivalent in age to the basal part of the Stevens sand. The average dip is 70°. The developed portion of the pool is $1\frac{3}{4}$ miles long with a maximum width of 500 feet. The north, south, and west limits have been established and development is continuing easterly.

16. "Ramona Field, Los Angeles and Ventura Counties, California," LOYAL E. NELSON, consulting geologist, Los Angeles.

The Ramona field is located 45 miles northwest of Los Angeles near Castaic Junction in the Santa Clara River Basin, Sec. 18, T. 4 N., R. 17 W., and Sec. 13, T. 4 N., R. 18 W.

Discovery was effected by The Texas Company's Kern 42-18, completed on April 19, 1945, from 150 feet of upper Miocene sand at 3,000 feet, flowing 196 barrels per day 29.3°. Twenty-four wells have been completed since discovery with initial rates ranging from 50 to 150 barrels per day.

The structure is a northeast trending and plunging anticline with north flank cut by the paralleling Holser thrust fault of 4,000–5,000 feet throw. Present development has proved an area ¼ mile wide by 1½ miles in length.

17. "Stratigraphic and Structural Features of the Ivanpah Quadrangle, Southeastern California," D. F. Hewett, United States Geological Survey, Washington, D C.

The following conclusions concerning this area of about 3,800 square miles in southeastern California, are based upon about 25 months field work between 1921 and 1934. The region records almost uninterrupted sedimentation during Paleozoic and Mesozoic time. Before this, there was a sedimentation (Pahrump series about 5,000 feet thick) and this rested upon a crystalline basement (Archean). The Tertiary record of sedimentation and volcanism appears to be wholly late Miocene or early Pliocene. Two major orogenies are recorded by thrust faults and normal faults. The first (Laramide late Cretaceous or early Tertiary) includes at least five major thrust faults along which early Paleozoic rocks generally rest upon upper Paleozoic or early Mesozoic rocks. Great masses of quartz-monzonite were intruded toward the close of the epoch and there was widespread mineralization. It was followed by profound erosion from early Eocene to upper Miocene time. The second orogeny (early Pliocene) followed a period of Mid-Tertiary sedimentation and volcanism. It is represented by a single great thrust fault, remnants of the upper plate of which have been mapped over an area of 20 by 30 miles. It was followed by normal faults and local sedimentation.

NEW ROCK-COLOR CHART FOR FIELD USE

A committee representing a number of geological societies and organizations has begun work on a new rock-color chart designed specifically for field use. The membership of the committee is as follows.

Parker D. Trask, representing the Geological Society of America

Ronald K. DeFord, representing the American Association of Petroleum Geologists

Joseph T. Singewald, Jr., and R. M. Overbeck, representing the Association of American State Geologists

Olaf N. Rove, representing the Society of Economic Geologists

E. N. Goddard, representing the United States Geological Survey

The first meeting of the committee was held on May 2, 1946, in Washington, D. C. Hugh D. Miser, of the Geological Survey, who had been instrumental in getting the work started, gave a brief account of the discussions and correspondence that led up to the organization of the committee. Ronald K. DeFord, who was unable to attend, sent a letter suggesting a general plan of procedure, and this letter was used as a basis for discussion. The following plans were agreed upon by the committee.

1. The rock-color chart is to be based on the Munsell color system, the most widely accepted system of color identification in the United States.

2. Simple color names of the ISCC-NBS (Inter-Society Color Council-National Bureau of Standards) method are to be used on the chart, insofar as is applicable to field use. This method has already been adopted by a large number of societies and organizations interested in color.

3. In addition to the color names, the Munsell hue, value, and chrome designations are to be put on the chart, for the use of any geologists who feel the need of numerical designations and fine color distinctions.

4. Sedimentary, igneous, and metamorphic rocks (both consolidated and unconsolidated) are to be included, and also well cuttings. If possible, both wet and dry rocks are to be included.

The committee is now engaged in collecting and classifying the widest possible range of rock specimens in order to determine the range of colors needed on the chart. The next meeting of the committee is to be held at the Chicago meetings of the Geological Society of America in December, 1946, and at that time, the following problems will be considered.

1. The number and range of colors, and the appropriate names to be used on the chart
2. The shape, size, and arrangement of the chart, the size of the color tabs, and whether holes in the chart should be used to facilitate comparisons with rock samples
3. The method and means of printing and distributing the chart

The committee will welcome any suggestions. The Munsell color system, as applied to rock colors, is discussed by DeFord—"Rock Colors," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 1 (January, 1944), pp. 128–37. The ISCC-NBS method of naming colors is described by Dean B. Judd and Kenneth L. Kelly, "Method of Designating Colors," *Nat. Bur. Standards Research Paper 1239* (September, 1939).

AT HOME AND ABROAD

T. L. Tapp is associated with Bennett and Sorrels, independent oil producers, and may be addressed at 2111 North Aydelotte, University Station, Shawnee, Oklahoma.

F. W. Mueller has resigned from his position as district geologist with the Skelly Oil Company, Houston, Texas, and has joined P. R. Rutherford as geologist.

James S. Kauffman, formerly with the Wilcox Oil Company, Tulsa, Oklahoma, is now with the Sinclair Prairie Oil Company in Tulsa.

J. L. Kalb, as assistant manager of the Tropical Oil Company in Colombia, has recently returned to Bogota following a business interlude in the United States and Canada. He is a former director and vice-president of the Creole Petroleum Corporation.

George M. Cunningham has been appointed manager of a new exploration department recently organized by the Standard Oil Company of California. Other members of the new department include W. S. W. Kew, chief geologist; S. H. Gester and W. F. Barbat, assistant chief geologists; G. C. Gester, consulting geologist; Phillip P. Gaby, consulting geophysicist; and W. P. Winham, G. L. Knox, and A. J. Solari as district superintendents of exploration.

Harry H. Arnold, Jr., has been appointed assistant manager of the Oklahoma-Kansas-Illinois division of The Texas Company, with headquarters in Tulsa, Oklahoma. Arnold has been general superintendent of the company's operations in Illinois.

H. E. Summerford is in charge of a new stratigraphic well-logging service, Casper, Wyoming. He was formerly district geologist for Kerr-McGee Oil Industries, Inc.

Walter E. Belt, Jr., has opened a consulting geological office in Houston, Texas. He recently resigned as geologist for the Southern Natural Gas Company, Jackson, Mississippi.

Glenn E. Crays has left the Texas Pacific Coal and Oil Company, Midland, Texas, and has accepted a position with the Creole Petroleum Corporation, Caracas, Venezuela.

J. Brian Eby, consulting geologist of Houston, Texas, recently toured war-torn Europe as a special editorial representative of the *Oil Weekly*. Two articles in the November 4 issue of this publication (Vol. 123, No. 10, pp. 8–17, and 28, 35) are based on these first-hand studies: "Austria's Critical Petroleum Situation," and "Oil at the Peace Conference."

Albert J. Ingham, who has been with Shell Oil Company, Inc., for the past 7 years, has accepted a position as assistant geologist with the Pennsylvania Bureau of Topographic and Geological Survey.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 30, NO. 12 (DECEMBER, 1946), PP. 2093-2096

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

MARIA SPENCER is now working in Nassau, Bahamas, for the Bahamas Oil Company, Ltd.

Commander RICHARD H. PENCE, U.S.N.R., is now on terminal leave and may be addressed: 3554 Carlin Avenue, Lynwood, California. Before the war he was with the Central Committee California Crude Oil Producers.

J. P. FOX has been elected to the board of directors of the Standard Oil Company of Texas.

JOHN HUBERT BUEHNER is out of the Army and working in the geological department of the Ohio Oil Company at Marshall, Illinois.

KENNETH C. ANDERSON and CHARLES R. GRICE are working in the geological laboratory of the Standard Oil Company of Texas at Midland, Texas.

PAUL H. DUDLEY, formerly of Long Beach, California, may be addressed in care of American Placers, Inc., 107 North 34th Street, Billings, Montana.

C. L. MCNULTY, JR., has resigned from the faculty of the department of geology at Southern Methodist University, Dallas, Texas, and has accepted appointment as associate professor of geology, North Texas Agricultural College, Arlington, Texas.

W. HARLAN TAYLOR has announced that he is entering the field of consulting and contracting geophysical service and has established the Taylor Geophysical Company. Headquarters of the company are temporarily situated at 1601 South Shepard Drive, Houston 6, Texas. During the past 13 years Taylor has been associated with the Petty Geophysical Engineering Company.

CLEMENTE GONZÉLES DE JUANA has resigned as consulting geologist to the Instituto Nacional de Obras Sanitarias (Venezuelan Government) to become professor of geology at the University of Caracas. He will teach petroleum geology and the geology of Venezuela. His new address is Apartado 1554, Caracas, Venezuela.

RUSKIN H. MEYER is employed by the Republic Natural Gas Company, 1155 First National Bank Building, Oklahoma City, Oklahoma.

CLIFFORD N. HOLMES, formerly with the U. S. Geological Survey, Baton Rouge, Louisiana, may be addressed in care of the department of geology of Yale University, New Haven, Connecticut.

HOLLIS D. HEDBERG, after 20 years spent in Venezuela, has been transferred to the New York office of the Gulf Oil Corporation, 17 Battery Place, New York City.

R. B. WHEELER has been transferred from Colombia to Venezuela, where his new address is: The Texas Company, Apartado 267, Caracas, Venezuela.

GLEN M. RUBY, of Hoover, Curtice & Ruby, Inc., New York, is in Cuba for a couple of months, after which he expects to spend most of his time on his Iowa farm, although he is not "laying down the pick to pick up the plow, but will keep one in each hand." Some months ago he took time from his oil-discovery work at Punta Arenas, Chile, to visit the Far East.

W. S. HOFFMEISTER, geologist for several years with the Carter Oil Company at Shreveport, Louisiana, has been transferred to the Carter Research Laboratory at Tulsa, Oklahoma.

Colonel O. F. KOTICK has been released from leave-of-absence status with the Tide Water Associated Oil Company in California and has joined the Regular Army, with the permanent rank of Major. His address is The Joint Chiefs of Staff, Army-Navy Petroleum Board, 2830 Navy Building, Washington 25, D. C.

The Rocky Mountain Association of Petroleum Geologists met, October 28, in the Empire Room of the Shirley-Savoy Hotel, Denver, Colorado. J. HARLAN JOHNSON spoke on the San Carlos Mountains of Chihuahua, illustrating his talk with color slides.

Meeting in the South American Room, Rice Hotel, Houston, Texas, on October 28, the Houston Geological Society heard FRED W. BATES speak on the "Geology of West Tepetate Oil Field, Jefferson Davis Parish, Louisiana."

KATHARINE W. CARMAN has resigned from her position as district geologist for the Great Lakes Carbon Corporation in the Illinois district.

Speaking before the Shawnee (Oklahoma) Geological Society, meeting in the Aldridge Hotel, Shawnee, on October 10, JACK DAVIES described the "Canol Project" and illustrated his talk with colored motion pictures.

HARRY H. POWER, in his article entitled "Petroleum Highlights in Venezuela," published in the October issue of the *Petroleum Engineer*, reports on his recent visit to South America.

HENRY KEPLINGER, of the consulting firm of Keplinger and Wanenmacher, Tulsa, Oklahoma, spoke on September 25 before the Oklahoma Society of Petroleum Engineers, Oklahoma City, on the subject "Appraisal of Oil Producing Properties." JOSEPH M. WANENMACHER, of the same firm, spoke on October 8 in Wichita Falls, Texas, before the North Texas Chapter of the American Petroleum Institute. The subject of his address: "Geology and Engineering Problems of the Hull Silk Field, North Texas."

M. G. CHENEY, Coleman, Texas, and J. V. HOWELL, Tulsa, Oklahoma, participated in the annual meeting of the Independent Petroleum Association of America held at Fort Worth, Texas, October 28–30. Howell addressed the meeting on the subject of "Known and Potential Sources of Supply of Petroleum in the United States." Cheney, past-president of the A.A.P.G., was one of a panel of experts who participated in a discussion of national oil policy.

JOSEPH L. BORDEN, geologist for many years at the Tulsa, Oklahoma, office of the Pure Oil Company, has been transferred to Durango, Colorado, where he has opened an office for the company.

V. ELVERT MONNETT, director of the School of Geology, University of Oklahoma, spoke at a recent meeting of the oil and gas division of Oklahoma City Chamber of Commerce. His subject: "The History and Future of Oil Development in Oklahoma."

HAROLD W. HOOTS has returned to his consulting office in Los Angeles, California, after spending several weeks in South America studying the geology of Peru.

EMMETT A. FINLEY, formerly employed in Jackson, Mississippi, by the Magnolia Petroleum Company, is now engaged as a field geologist for the Creole Petroleum Corporation in Caracas, Venezuela.

CARL A. MOORE, associate professor of geology at the University of Oklahoma, addressed the Oklahoma City Geological Society at a special noon luncheon on Tuesday, October 15. His subject was "The South Moore Oil Field, Cleveland County, Oklahoma."

BURTON W. COLLINS is a geologist with the New Zealand Geological Survey, 156 The Terrace, Wellington, New Zealand. Previous connections include the Island Exploration Company, New Guinea in 1937 and 1938; the New Zealand Petroleum Company in 1938–1942; and the Dominion Compressed Yeast Company, Auckland, since 1942.

LEO HENDRICKS, who has been a member of the staff of the Bureau of Economic Geology, Austin, Texas, since 1937, has resigned to join the faculty of Texas Christian University.

CEVAT EYÜP TAŞMAN of Ankora, Turkey, now holds the position of chief petroleum adviser in the M. T. A. Institute.

ROBERT W. LANGE has left Amerada Petroleum Corporation and has opened a consulting office at 108 Grand Street, Garden City, Kansas.

JACK GARDNER has resigned his position with Gulf Oil Corporation to accept a position with the Photographic Intelligence Center, U. S. Navy Receiving Station, Washington 25, D. C.

M. F. PRYOR has opened an office as a consulting geologist at his home in Great Bend, Kansas.

F. E. METTNER has resigned from the Sunray Oil Company and has returned to his home in Wichita, Kansas.

KILBURN E. ADAMS, JR., has succeeded W. M. Guthrey as Kansas district geologist, at Wichita, for The Texas Company. Guthrey has been transferred to the Tulsa office.

BEN HURLBUTT and FRANK HERRING announce the formation of Ben-Franklin Exploration, Inc., specializing in core drilling. They are located at 805 Petroleum Building, Wichita, Kansas.

JACK H. HEATHMAN is vice-president of the H. H. & B. Drilling Co., Inc., 700 Petroleum Bldg., Wichita, Kansas.

DAN E. BOONE, Halliburton Oil Well Cementing Company, Duncan, Oklahoma, spoke on "Portable Electric Logging Equipment" at the luncheon meeting of the Tulsa Geological Society on November 8.

K. R. PARSONS has moved to Stanford University, where his new address is Building 312, Stanford Village, Stanford University, California.

E. A. MCCULLOUGH, formerly with the Phillips Petroleum Company, Midland, Texas, is now with the Sunray Oil Corporation, Box 941, Midland, Texas.

FREDERICK T. HOLDEN is now district geologist in Mississippi and Alabama for the Carter Oil Company. Formerly in Shreveport, Louisiana, he may now be addressed at Box 1490, Jackson, Mississippi.

K. F. HUFF, International Petroleum Company, Ltd., has moved from Guayaquil, Ecuador, to Lima, Peru, where his address is Box 1081.

JOHN A. YOUNG, JR., has left the Sun Oil Company to accept appointment as assistant professor of geology at Syracuse University, Syracuse, New York.

JOHN J. RUPNIK, formerly with the Sun Oil Company, Beaumont, Texas, has accepted a position as geophysicist with the Sinclair Prairie Oil Company, Box 521, Tulsa 5, Oklahoma.

EUGENE F. BOEHMS, recently district geologist for the American Trading and Production Corporation, Abilene, Texas, is now associated with the Woodley Petroleum Company, 712 Alexander Building, Abilene.

Major LOUIS DEGOES is overseas with the AAF Air Transport Command. His address is 1500th AAFBU-P.D.-A.T.C., APO 953, c/o P.M., San Francisco, California.

NORMAN C. SMITH has moved from Somerville, New Jersey, to Tallahassee, Florida, where is he employed by the Humble Oil and Refining Company.

ERNST KUNDIG, formerly of Lima, Peru, may now be addressed: Bataafsche Petroleum Mij., Carel van Bijlandslaan, The Hague, Holland.

J. R. REEVES is now with the Lee Geophysical Exploration and Research Corporation, Box 632, Cisco, Texas. He was formerly with the National Geophysical Company, Dallas, Texas.

DAVID K. LANGFORD has a consulting geological office at 627 Hamilton Building, Wichita Falls, Texas.

REAGAN TUCKER has moved from Corpus Christi to San Antonio, Texas, where he has a consulting geological office at 528 Milam Building.

FRANK W. ROHWER, formerly with the Pioneer Oil Corporation, is now an independent consulting geologist, and may be addressed at 1433 Pine Street, Boulder, Colorado.

KENDALL E. BORN, for many years a member of the State Division of Geology, Nashville, Tennessee, has resigned to accept an assistant professorship in the department of geology at the School of Mines and Metallurgy, Rolla, Missouri.

DOUGLAS D. HOWARD is doing petroleum geological work in South America, having recently joined the staff of the Creole Petroleum Corporation, Apartado 172, Maracaibo, Venezuela.

J. R. LOCKETT of the Ohio Fuel Gas Company, Columbus, Ohio, spoke before the Appalachian Geological Society on October 13, in Charleston, West Virginia, on "The Development of Structure in the Basin Areas of Northeastern United States."

CARL T. ANDERSON, formerly an independent of Wichita Falls, Texas, has taken charge of the Republic Natural Gas Company office in Oklahoma City, Oklahoma.

J. C. HEGGBLOM may be addressed in care of the Bahamas Exploration Company, Ltd., Nassau, Bahamas, B.W.I.

THOMAS C. WILSON has completed a three-month vacation in the United States and is now back with the Venezuelan Atlantic Refining Company, Apartado 893, Caracas, Venezuela.

FRANCIS A. HALE has left Geophysical Service, Inc., Dallas, Texas, in order to accept a position as seismologist with the Richmond Exploration Company, Sociedad a Camejo 16, Caracas, Venezuela.

B. B. BRADISH may be addressed in care of the Tropical Oil Company, Bogota, Colombia.

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INDEX OF VOLUME 30 (1946)

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

VOLUME 30

JANUARY—DECEMBER 1946

PART I

PAGES 1-1076

ASSOCIATION HEADQUARTERS, BOX 979, TULSA 1, OKLAHOMA

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MONTHLY

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CONTENTS OF VOLUME 30 (1946), PART I

NUMBER 1 (JANUARY)

NUMBER 2 (FEBRUARY)

NUMBER 3 (MARCH)

NUMBER 4 (APRIL)

NUMBER 5 (MAY)

NUMBER 6 (JUNE)

REVIEW OF EXPLORATION AND DEVELOPMENT IN 1945

ERRATA

PAGE 717. Figure 2 should not have been used. The correct Figure 2 is printed on page 1934.

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

GAYLE SCOTT, *Editor*

TEXAS CHRISTIAN UNIVERSITY, FORT WORTH 9, TEXAS

VOLUME 30

JANUARY—DECEMBER 1946

PART II

PAGES 1077-2120

ASSOCIATION HEADQUARTERS, BOX 979, TULSA 1, OKLAHOMA

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

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(The foregoing officers, together with the *Past-President*, MONROE G. CHENEY, Coleman, Texas, constitute the Executive Committee)

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(Representatives' terms expire immediately after annual meetings of the years shown in parentheses)

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John W. Inkster (1947), Wichita, Kan.
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Henryk B. Stenzel (1947), Austin, Tex.

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Secretary-Treasurer: EDWARD A. KOESTER
Editor: GAYLE SCOTT

(The foregoing officers, together with the *Past-President*, IRA H. CRAM, constitute the Executive Committee)

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NUMBER 8 (AUGUST)

NUMBER 9 (SEPTEMBER)

NUMBER 10 (OCTOBER)

NUMBER 11 (NOVEMBER)

NUMBER 12 (DECEMBER)

ERRATA

PAGE 1508. First center heading should be: B. JURASSIC PROSPECTS.
Second center heading should be: C. PERMIAN, etc.
Third center heading should be: D. LOWER CRETACEOUS, etc.
PAGE 1512. Center heading should be: A. JURASSIC PROSPECTS.
PAGE 1513. Center heading should be: B. CARBONIFEROUS, etc.
PAGE 1514. First center heading should be: B. JURASSIC.
Second center heading should be: C. PERMIAN, etc.
PAGE 1589. Discussion should be: TECTONIC FRAMEWORK OF NORTHWESTERN SOUTH AMERICA.

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
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Midland Savings Building

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Heiland Research Corporation

2nd Vice-President - - - - Robert McMillan
Geophoto Services, Inc.
136 East Twentieth Ave.

Secretary-Treasurer - - - - - - A. W. Cullen
1024 Continental Oil Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

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ILLINOIS GEOLOGICAL SOCIETY

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Box 537, Mt. Vernon

Secretary-Treasurer - - - - John B. Patton
Magnolia Petroleum Company
Box 535, Mt. Vernon

Meetings will be announced.

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Skelly Oil Company

Vice-President - - - - - - - Paul A. Harper
Cities Service Oil Company

Secretary-Treasurer - - - Francis E. Mettner
Transwestern Oil Company
605 Union National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

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Union Producing Company

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

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TALLAHASSEE, FLORIDA

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The California Company

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Meetings will be announced. Visiting geologists and friends are welcome.

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Sun Oil Company
Evansville, Ind.

Meetings will be announced.

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Secretary-Treasurer - - - - - Philip R. Allin
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Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

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Secretary - - - - - - - - - - Lloyd D. Traupe
Ohio Oil Company

Treasurer - - - - - - - - - - D. E. Newland
Magnolia Petroleum Company

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

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Capitol Savings and Loan Bldg., Lansing
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Secretary-Treasurer - - - - Charles K. Clark
Pure Oil Company
402 2d Natl. Bank Bldg., Saginaw
Business Manager - - - Kenneth A. Gravelle
Gulf Refining Company, Box 811, Saginaw

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY

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Mellen & Monsour
Box 2571, W. Jackson Sta.

Vice-President - - - - - - - - J. B. Wheeler
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - - - H. L. Spyres
Skelly Oil Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY

ARDMORE, OKLAHOMA

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Independent, Box 156

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

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Skelly Oil Company

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Shell Oil Company, Inc.
965 First National Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

SHAWNEE GEOLOGICAL SOCIETY

SHAWNEE, OKLAHOMA

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Oklahoma Seismograph Company

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Atlantic Refining Company

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Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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TULSA, OKLAHOMA

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Independent, Beacon Building
2nd Vice-President - - - - - John C. Maher
U. S. Geological Survey
Secretary-Treasurer - - - - - John R. Crain
Ashland Oil and Refining Company
Editor - - - - - - - - Robert F. Walters
Box 661, Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY

CORPUS CHRISTI, TEXAS

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The Texas Company, 902 Jones Building

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Sinclair Prairie Oil Company, Box 480

Secretary-Treasurer - - - - - O. G. McClain
Consultant, 224 Nixon Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS GEOLOGICAL SOCIETY

DALLAS, TEXAS

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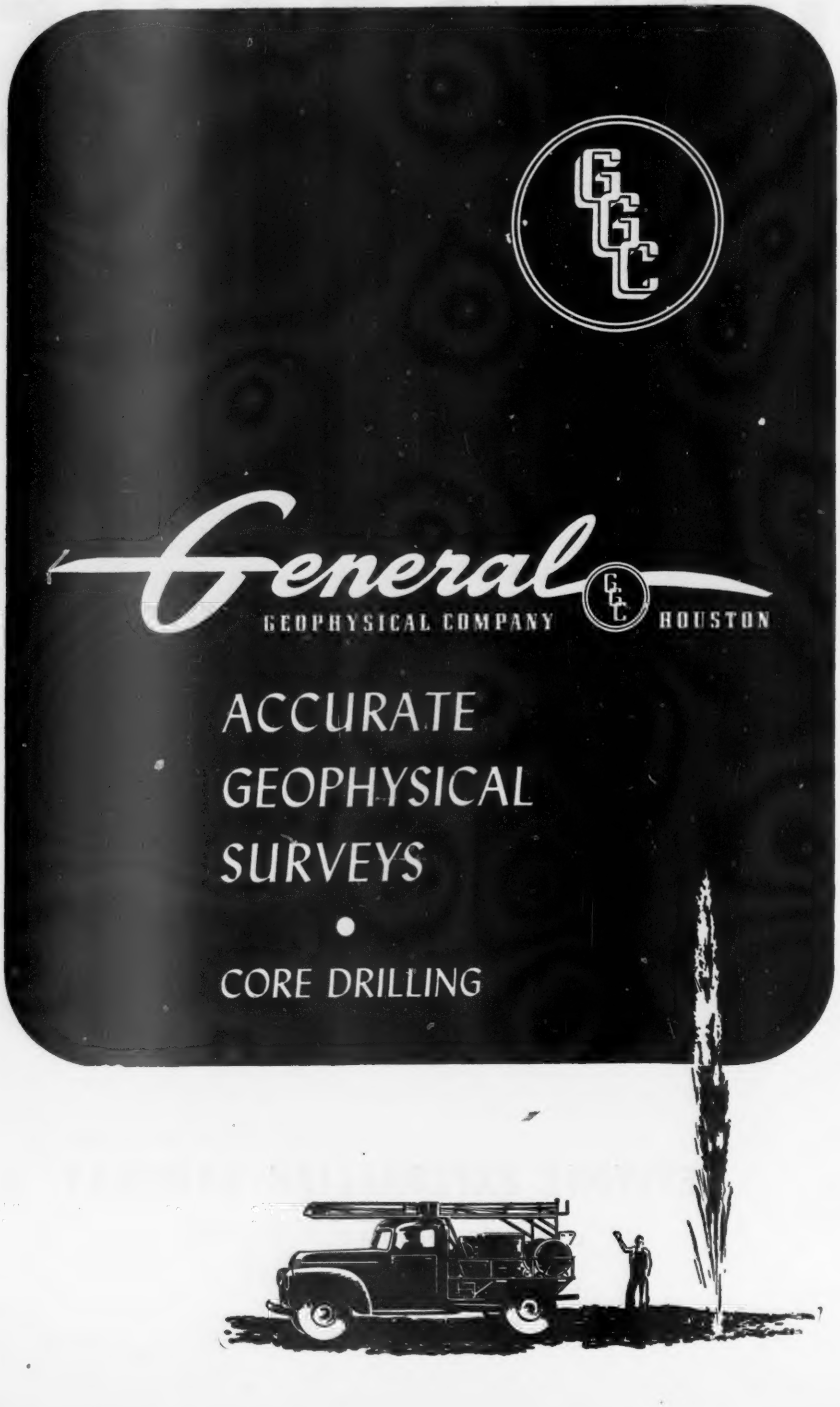
DeGolyer and MacNaughton, Continental Building
Secretary-Treasurer - - - - John M. Clayton
Seaboard Oil Company, 1400 Continental Building
Executive Committee - - - - Fred H. Wilcox
Magnolia Petroleum Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.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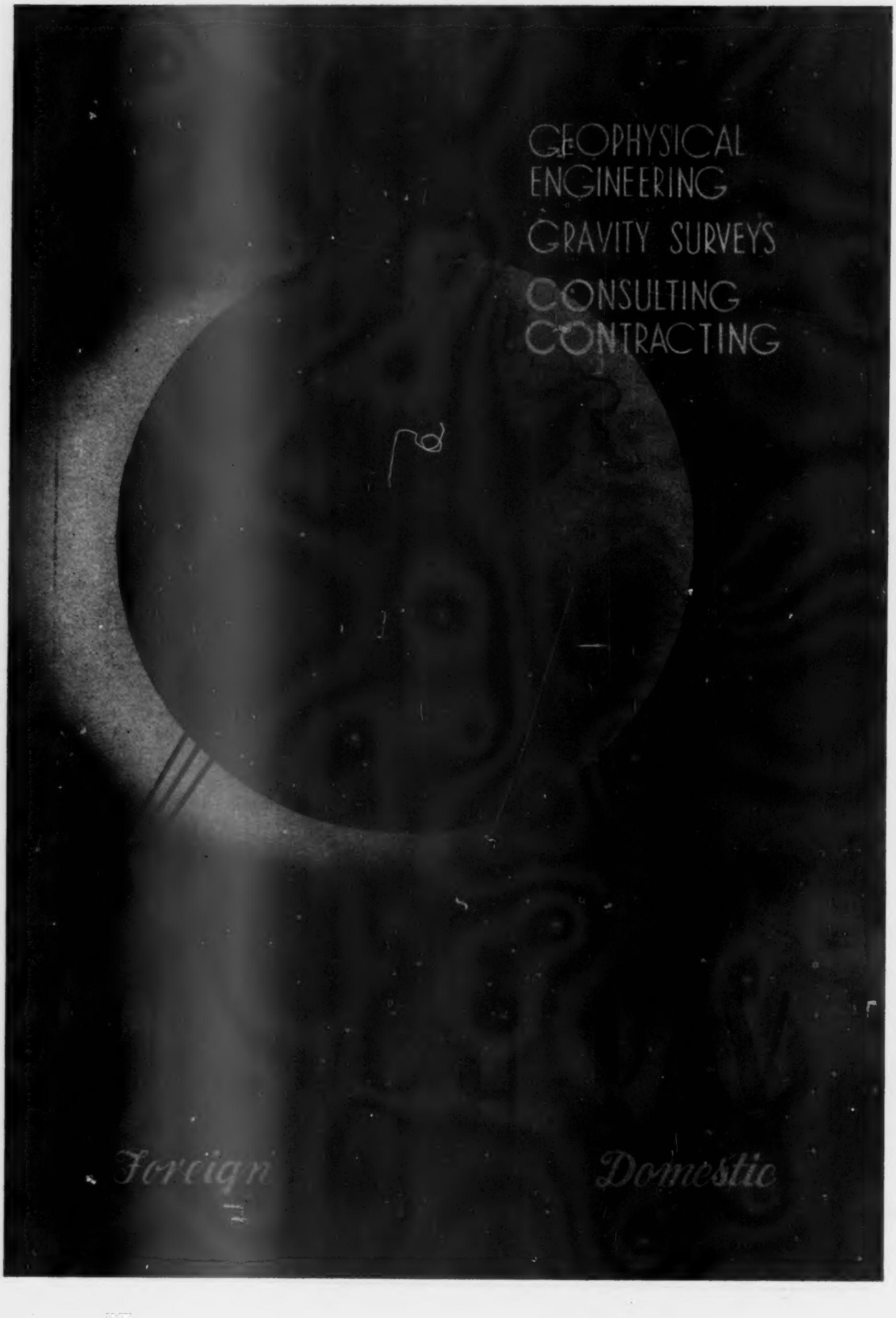
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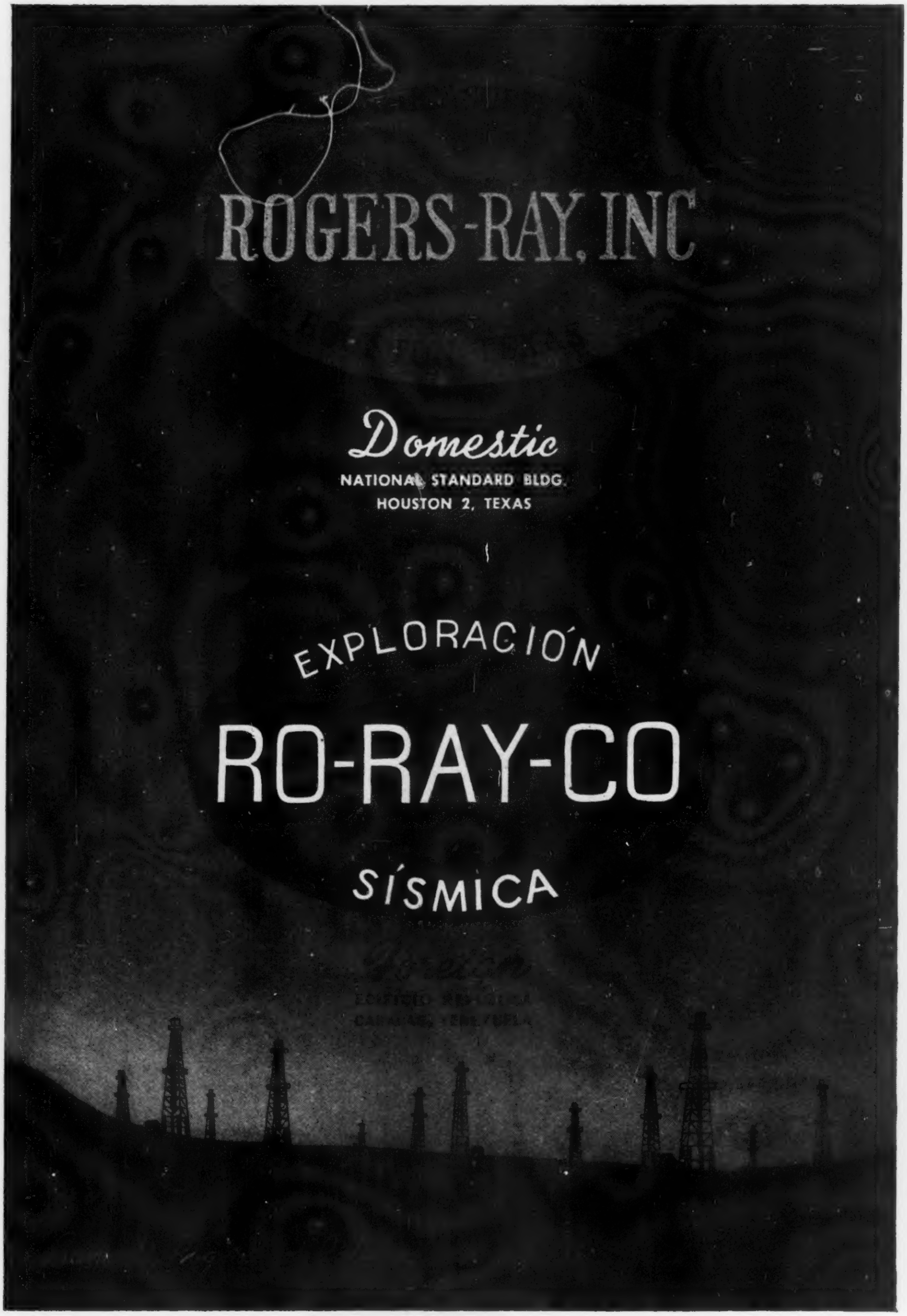
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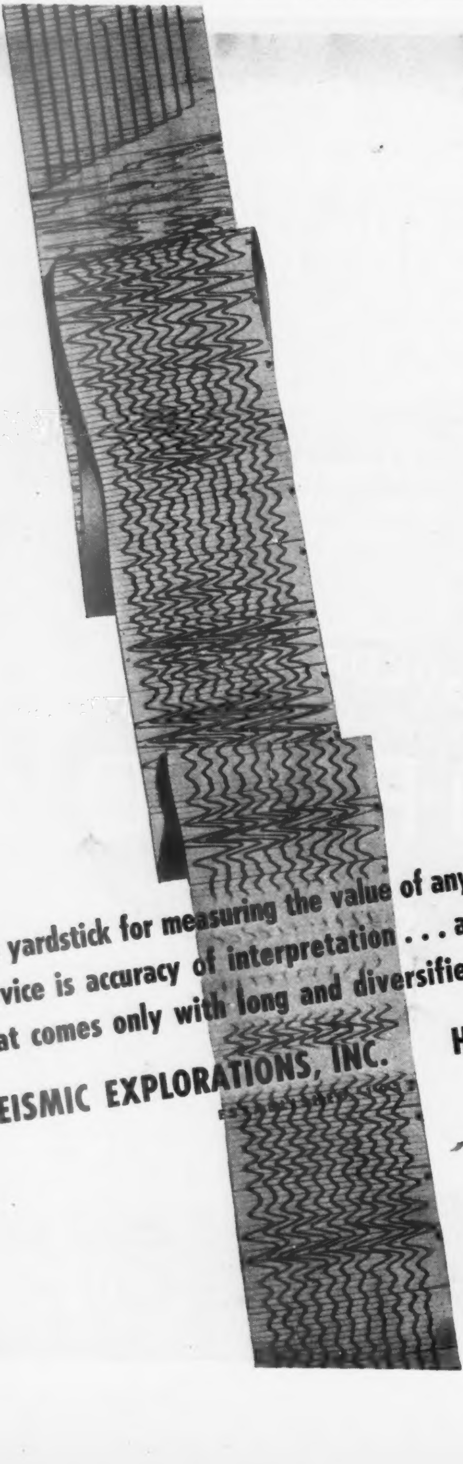

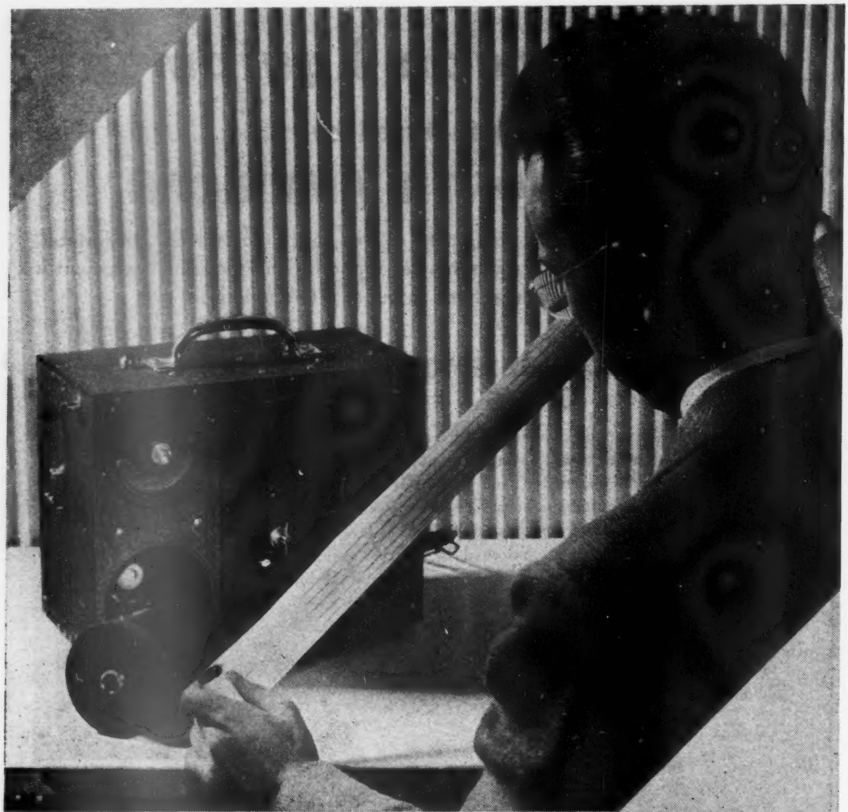

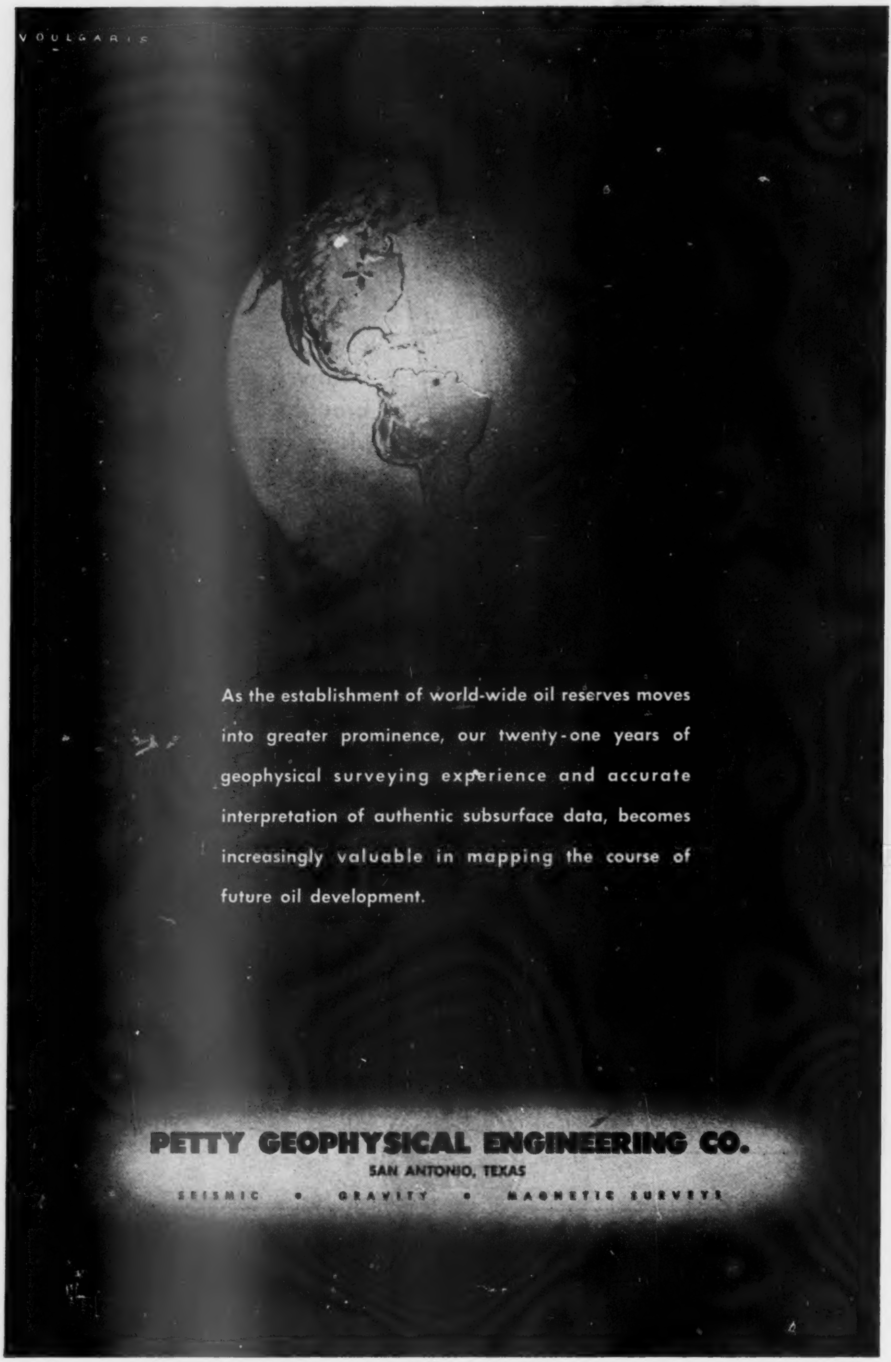
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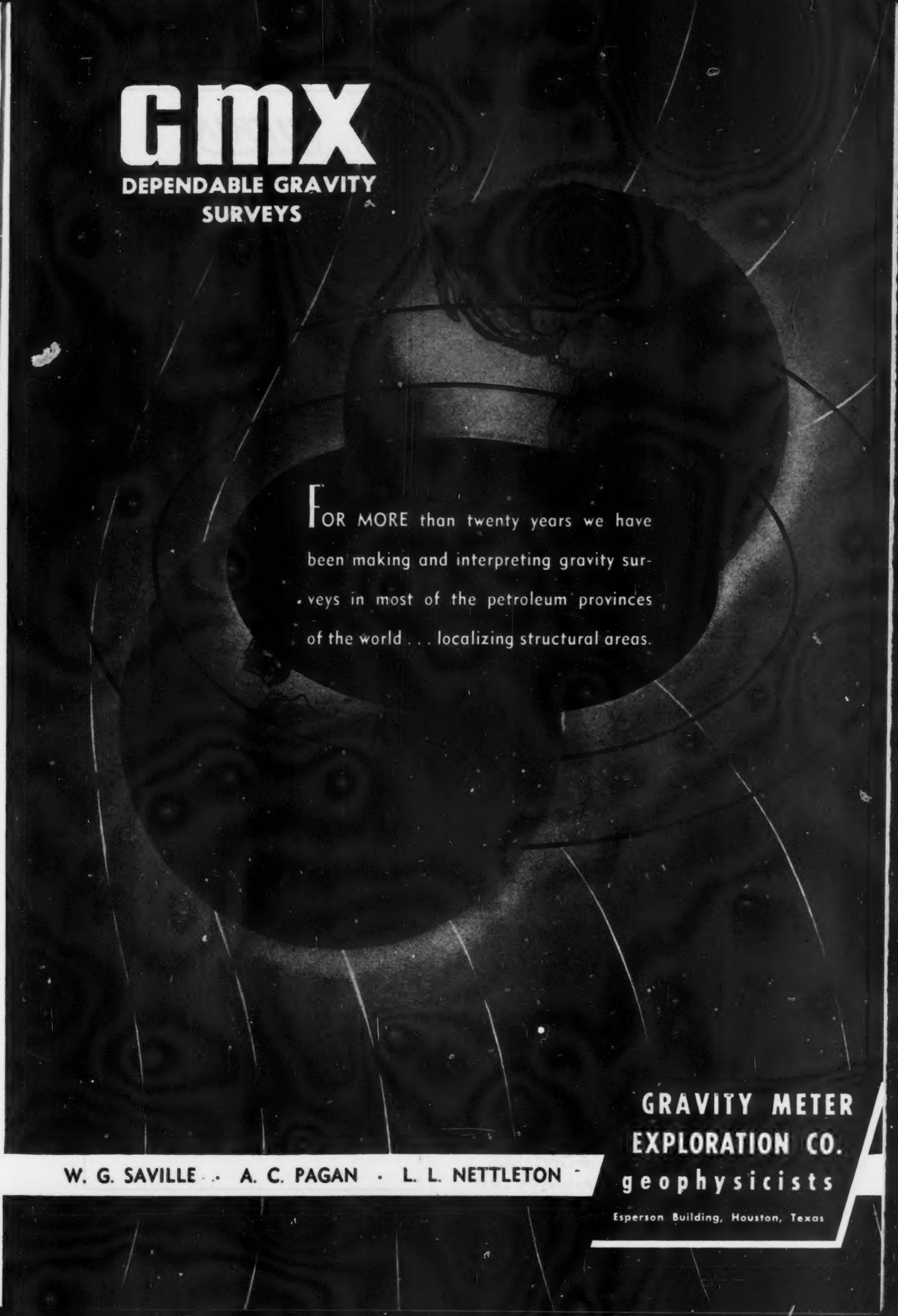
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NO. 11—134 pp. ARK.: Pennsylvanian. GEN.: Evaluation of petroleum index of refraction; colorimetric determination of oil open-space replacements. KAN. and OKLA.: Source beds. RUSSIA: Urals. TEX.: Laredo.

NO. 12—129 pp. ARABIA: "Black Sea" conditions in Arabian Sea. KAN.: Permian. N. Y.: Oriskany. OKLA.: Permian. PA.: Oriskany. TEX.: Sand Hills, Crane Co.

1938 VOL. XXII.—Each number .... ($1.00) 1.50

NO. 4—124 pp. GEN.: Appalachian field history; bibliography of structure maps and sections of oil states; folds in three dimensions. MICH.: Oil and gas.

NO. 5—116 pp. GEN.: Future of geologist; Oriskany sandstone petrology; geological limitations to oil law. N. MEX.: New section of Trinity age.

1939 VOL. XXIII.—1,922 pp. 12 Nos. Each number .... ($1.00) 1.50

NO. 1—120 pp. CALIF.: Reef Ridge shale; Santa Maria Valley field. NEB.: Agate anticline. UTAH: "Park City" beds, Uinta Mts.

NO. 2—160 pp. LA.: Vicksburg fauna. OKLA.: Keokuk pool. TEX.: Harris Co.; heaving shale. UTAH: Washington Co.

NO. 3—180 pp. LA.: Lisbon. OKLA.: Osage. TEX.: McFadden Beach.

NO. 4—164 pp. CALIF.: Ridge Basin. LA.: Barataria Bay. MO.: Bainbridge formation. MONT.: Baker-Glendive anticline. OKLA.: Verden shoestring. TEX.: Orange field; salt erosion, Gulf. U.S.S.R.: Salt domes. WYO.: Wind River Canyon.

NO. 5—140 pp. GENERAL: Two tilts. KAN.: Greenwich pool. OKLA.: Dora pool. PERU: Agua Caliente anticline. TEX.: Travis Peak formation; Fairbanks and Satsuma fields. TURKEY: Southern.

NO. 6—218 pp. REVIEW OF DEVELOPMENTS.

NO. 7—180 pp. GEN.: Rock units. KAN.: Hugoton gas. OKLA.: Arbuckle asphalt. TEX.: Panhandle gas; Carlos structure and Ferguson Crossing, Grimes and Brazos Cos.

NO. 8—124 pp. ARK.: Basilosaurus. CALIF.: Potrero Hills gas. GEN.: Rocky Mtns.; black shale. KAN.: Loess. LA.: Stream patterns. S. DAK.: Pennington Co. TEX.: Ben Bolt and Magnolia City fields, Jim Wells Co.; Muralla field, Duval Co. TRINIDAD.

NO. 9—148 pp. GEN.: Isostatic layer; electrical logging; Gulf datum planes. ILL., IND., KY.: Coals; Salem field, Marion Co. MISS.: Jackson Eocene, TEX.: Proration.

NO. 10—164 pp. ALA.: Citronelle. CALIF.: Wasco field, Kern Co. GEN.: Oligocene-Miocene. ILL.: Basin fields; Pennsylvanian; Cambrian inlier. N. MEX.: Salado formation. TEX.: Goldsmith field, Ector Co.; Salado. WYO.: Wind River Canyon.

NO. 11—148 pp. FLA.: Everglades deep test. GEN.: Permian; marine and non-marine sediments. NEB.: Permian. N. MEX.: Castile salt, potash, anhydrite. TEX.: Gulf Coast; Amelia field, Jefferson Co.; Permian.

NO. 12—172 pp. GEN.: Drilling time; Cincinnati arch. KAN.: Permian. KY.: St. Peter; McClosky productive areas. LA.: Starks field, Calcasieu Parish.

1940 VOL. XXIV.—2,232 pp. 12 Nos. Paper. Each number........................($1.00) 1.50

NO. 3—208 pp. GEN.: Gulf Coast Miocene; barium in Appalachian brines. LA.: Miocene; interior salt domes. OHIO: Secondary recovery. OKLA.: Morrow group, Adair Co. TEX.: Apco structure, Pecos Co.: Sejita structure, Duval Co.

NO. 4—148 pp. ARK.: Dorcheat pool, Columbia Co. AUSTRALIA: Permian. CALIF.: Whittier Quadrangle; Kettleman Hills; Paloma field, Kern Co. COLO.: Permian. LA.: Sparta-Wilcox. MINN.: Pre-Cambrian, Cambrian. OHIO: Paleozoic, pre-Cambrian, Delaware Co. OKLA.: Osage, Washington, Nowata Cos.; deepest well, Washita Co. TEX.: Lissie and Beaumont, Gulf Coast; Sparta-Wilcox; shoreline, Brazoria Co.

NO. 5—188 pp. GEN.: Mississippian, Eastern Interior; geochemical exploration.

NO. 6—204 pp. RECENT DEVELOPMENTS.

NO. 7—196 pp. CALIF.: Rio Bravo field, Strand field, Kern Co. TEX.: Cretaceous ammonoids. WYO.: Oil-field waters.

NO. 8—176 pp. GEN.: Exploration methods; young graduates and field experience; source of hydrogen; underground gas storage. IA.: Wildcat well, Union Co. TEX.: Henderson pool. Clay Co.; K.M.A. field, Wichita Co.

NO. 9—176 pp. CANADA: Turner Valley Paleozoic limestone. CALIF.: Bakersfield Eocene coal. COLOMBIA: Jurassic-Cretaceous. GEN.: Radioactivity of rocks; GULF: Cook Mtns. N. MEX.: Caballos novaculite. TENN.: Lower Ordovician (St. Peter). VENEZUELA: Jurassic-Cretaceous. W. INDIES: Paleogene of Barbados.

NO. 10—160 pp. CALIF.. History; Eocene Yokut sandstone. GEN.: Paleontology. KAN.: Hugoton field porosity, permeability. TEX.: Saxet field, Nueces Co.; Rogers pool and Bonita discovery, Montague Co.; Aspermont pool, Stonewall Co.

NO. 11—204 pp. CALIF.: San Joaquin Valley Eocene. GEN.: Carbohydrates of oil and coal; unconformities and accumulation. LA.: Wilcox Eocene; Neale, Beauregard Parish. MICH.: Buckeye, Gladwin Co. MISS.: Surface. OKLA.: Ramsey, Payne Co.; Billings, Noble Co. TEX.: Wilcox Eocene; Pittsburg, Camp Co. W. VA.: Devonian.

NO. 12—164 pp. CALIF.: Miocene fishes, Torrance field. GEN.: Water cones; Permian crude. LA.: Gulf heavy minerals. MICH.: Isopach, Ellsworth-Traverse limestones. OKLA.: Structural interpretation, gravity anomalies. TEX.: Gulf heavy minerals; Hoffman field, Duval Co.; Jones Co. TRINIDAD: Los Bajos fault.

1941 VOL. XXV.—Each number..($1.00) 1.50

NO. 12—167 pp. GEN.: Shadowgraphic maps; free-oil deposition; traceslip faults; stratigraphy; radioactivity logging. N. MEX.: Sacramento Mtns. Mississipian.

1942 VOL. XXVI.—1,893 pp. 12 Nos. Paper. Each number........................($1.00) 1.50

NO. 1—152 pp. APPAL.: Geochemistry, gas. GEN.: Silurian, Mississippi Basin; unconformities; spacing. KAN.: McLouth field, Jefferson and Leavenworth Cos. N. MEX.: Salado formation, potash; Seven Rivers formation, Eddy Co. S. DAK.: Viola graptolites, Black Hills. VENEZUELA: Ortiz and Guarumen sandstones.

NO. 2—152 pp. CALIF.: Stratigraphy; Cretaceous; Del Valle field, Los Angeles Co. GEN.: Free oil accumulation. TEX.: Sewell-Eddleman area, Young Co.; Permian paleogeography; Eocene, Zapata Co.; Washburn field, La Salle Co.; McKee and Waddell sands, Simpson Ordovician, West Texas. UTAH: Laccolithic mountains, traps.

NO. 3—228 pp. CALIF.: Earthquake, Dominquez field, Los Angeles Co. GEN.: Member list; auditor's report. KAN.: Patterson pool, Kearny Co. MONT.: Madison Mississippian. N. DAK.: Stratigraphy. RUSSIA: Artinskian Permian. TEX.: Pre-Cretaceous, Edwards Plateau; Barnhart field, Reagan Co.

NO. 5—204 pp. CALIF.: Sutter Buttes. COLOMBIA: Honda district. GEN.: Pseudo-abyssal sediments; salty ground waters, Atlantic and Gulf coasts; oil-field waters; annual reports. MONT.: Cedar Creek anticline. TEX.: Silurian graptolite, Crane Co.

NO. 6—216 pp. RECENT DEVELOPMENTS

NO. 7—132 pp. ARK.: Developments; Midway field, Lafayette Co. GEN.: Annual addresses; exploration; geology, war, peace; teaching; drilling-time logs; appraisals, oil reservoirs. GULF: Tertiary microfossils. LA.: Developments.

NO. 8—124 pp. COLO.: Gore area. GEN.: Discovery methods. MONT.: Oil-field water. N. DAK.: Stratigraphy. TEX.: Ellenburger; Pennsylvanian anhydrite.

NO. 9—136 pp. ARK.: Schuler field, Union County. NEB.: Cretaceous. TEX.: Well spacing, Columbia field, Brazoria Co.

NO. 10—140 pp. CALIF.: Crocker Flat, Temblor Range. COSTA RICA: Amoura shale. GEN.: Lantern-slide copy. ILL.-IA.: Pennsylvanian. ILL.-IND.: Chester sandstone; New Harmony field. LA.: Morehouse Paleozoic. N., S. DAK.: Regional. TEX.: Payton pool, Pecos and Ward Cos.

NO. 11—98 pp. GEN.: Stratigraphical analysis and environmental reconstruction. TEX.: Graptolites, Crane Co.

NO. 12—98 pp. GEN.: Engineering geology; calculating thickness; annual index.

1943 **VOL. XXVII.**—1,674 pp. 12 Nos. Paper. Each number........................($1.00) 1.50

NO. 4—154 pp. MEX.: Upper Jurassic. ROCKY MTNS.: Structure. TEX.: Wasson field, Yoakum and Gaines Cos.; Embar field, Andrews Co. VA.: Natural coal gas.

NO. 5—134 pp. CALIF.: Tertiary. GEN.: Annual reports. GULF: Tuscaloosa formation. KAN.-OKLA.: Desmoinesian, Missourian. MICH.: Thunder Bay Traverse rocks. S. DAK.: Rapid City water wells. TEX.: Seguin formation; Dockum conglomerates.

NO. 6—172 pp. RECENT DEVELOPMENTS.

NO. 7—152 pp. GEN.: Annual addresses; discovery thinking; geology, paleontology, geophysics, reserves, discoveries, economics, war; developments, SE. U.S.; cabletool logs.

NO. 8—136 pp. LA.: Anse La Butte, St. Martin Ph.; Jennings field, Acadia Ph. TENN.: Structure. TEX.: L. Cret. foraminifera and ostracoda; ground water at Houston.

NO. 9—112 pp. GEN.: Marine micro-organisms and petroleum; faults. TEX.: Pre-Trinity. W. VA.: Metamorphism of coal.

NO. 10—120 pp. CALIF.: Santa Maria district; Eocene, Chico Martinez area. GREAT PLAINS: Big Snowy group. OKLA.: Simpson graptolites. ROCKY MTNS.: Crude oils.

NO. 11—160 pp. GEN.: Aerial photographs. GULF: Jurassic. VA.: Deep well, Russell Co. W. VA.: Deep well, Harrison Co.

NO. 12—112 pp. CALIF.: Radiolarites, Santa Maria basin. GEN.: Chemical analysis of crudes. N. DAK.: Tertiary; Williston basin. OKLA.: Spavinaw granite. VENEZUELA: Fossils in metamorphics.

1944 **VOL. XXVIII.**—1,812 pp. 12 Nos. Each number............................($1.00) 1.50

NO. 3—148 pp. ARK.: Developments, 1942. GEN.: Membership; audit. LA.: Developments, 1942. MEX.: Northern geology.

NO. 4—128 pp. CALIF.: Cretaceous and Paleocene, Santa Lucia Range. KY.: "Corniferous," Estill Co. LA.: Grabens; developments, 1942. TEX.: Pecan Gap, Wolfe City, and Annona formations; highest structural point; grabens.

NO. 5—124 pp. GEN.: Annual reports; velocity corrections; reserve estimates. GULF: Cotton Valley beds.

NO. 6—196 pp. RECENT DEVELOPMENTS. COLOMBIA: Free oil in ammonites. OKLA.: Viola graptolites.

NO. 7—180 pp. CALIF.: Tumey sandstone, Fresno Co.; exploratory wells. GEN.: Annual addresses: radioactivity and petroleum genesis; paleoecology, Middle Permian. MIDDLE EAST: Oil mission. MISS.: Field and salt-dome names. OHIO: Petroliferous iron ore. OKLA.: Broken Arrow coal, Rogers, Wagoner, and Tulsa Cos. TEX.: Miocene; elasticity of reservoir, E. Tex.; dolomite porosity in Devonian, W. Tex.

NO. 8—172 pp. COLOMBIA: Thrust fault. GEN.: Data on oil reserves. MEX.: Cretaceous. WYO.: Como Bluff anticline, Albany and Carbon Cos.

NO. 9—168 pp. GEN.: Stratigraphic thickness in parallel folds. GULF: Oligocene; Anahuac formation. LA.: Structure of deep domes. MO.: Bourbon High, Crawford Co.

NO. 10—144 pp. ARGENTINA: Tupungato field, Mendoza. CHINA: General geology; Red Basin, Szechuan province. E. INDIES: Sedimentary basins. GEN.: Petroleum distribution; origin and accumulation; elevations with plane table and speedometer. ILL.: Devonian subsurface; Sandoval pool, Marion Co. TEX.: Concord salt dome, Andrews Co.; fossils in Buda limestone, Denton Co.; Fullerton pool, Andrews Co.

NO. 11—112 pp. APPAL.: Underground gas storage. ARK.: Moorefield formation and Ruddell shale, Batesville district. COLOMBIA: Thrust fault. NEW MEX.: Upper Permian Ochoa series, Delaware basin. TEX.: Upper Permian Ochoa; salt diffusion in Woodbine sand; ammonoids in upper Cherry Canyon, Delaware group; South Tyler, and Sand Flat fields, Smith Co. VENEZUELA: Fusulinids, La Quinta formation.

NO. 12—140 pp. FLA.-GA.: Stratigraphy, structure. GEN.: Index; reservoir data.

1945 **VOL. XXIX.**—1,824 pp. 12 Nos. Each number..............................($1.00) 1.50

NO. 2—128 pp. GEN.: Mississippian and Pennsylvanian of N. Amer.; size distribution of sand. LA.: Ruston gas field, Lincoln Parish. OKLA.: Thrust faulting, Arbuckle Mtns. TEX.: Cretaceous, Tyler basin; South Houston salt dome and oil field, Harris Co.; crystalline rocks in deep well, Winkler Co.; deep test, Moore Co.

NO. 3—160 pp. GEN.: Maddox spoon; origin of petroleum; members; financial. TEX.: Rise of water level to defective gas well, Harris Co.; Deep test, Culberson Co.

NO. 4—64 pp. ARK.: Calhoun field, Columbia Co. GEN.: Paleogeographic and palinspastic maps. MONT.: Jurassic Ellis formation. OKLA.: Graptolites, Carter Co. TEX.: Lower Ordovician and Upper Cambrian.

NO. 5—152 pp. GEN.: Annual reports; Wallace Pratt, Powers medalist; college geology students. KAN.: Ness Co. MICH.: Silurian brine, Bay City. S. AMER.: Oil possibilities.

NO. 6—228 pp. RECENT DEVELOPMENTS. TEX.: New Hope field, Franklin Co.; Bacon limestone, E. Tex.

NO. 7—208 pp. ATLANTIC COASTAL PLAIN: Subsurface. CALIF.: Upper Cretaceous in Great Valley. GEN.: Presidential addresses; middle Jurassic in Western Interior; geological calendar. MISS.: Upper Cretaceous fossils from wells. OKLA.: Graptolites, Carter Co. TEX.: Igneous rocks from deep wells. W. Tex.

NO. 8—168 pp. ALBERTA: Reservoir, Turner Valley. COLOMBIA: Petroleum geology. GEN.: Time of oil accumulation; textural standard for sample logs; research in exploration. LA.: Ground-water geology, Camp Polk. MD.: Deep test, Wicomico Co. UTAH: Mississippian and Pennsylvanian, Dry Lake, Logan Quadrangle.

NO. 9—144 pp. GEN.: Recent sedimentation and search for petroleum; vertical source in oil and gas accumulation. GULF COAST: Sedimentation. MONT.: Marine Jurassic, Sweetgrass arch. TEX.: Pre-Permian axes of deposition, W. Tex.

NO. 10—160 pp. GEN.: Radioactivity, organic content, sedimentation; photography of megafossils; research program. ORE.: Geology and oil and gas. TEX.: Subsurface Lower Cretaceous, S. Tex. WASH.: Geology and oil and gas.

NO. 11—156 pp. ALBERTA: Cretaceous of Vermilion area. COLO.: Las Animas arch, Lincoln, Cheyenne, Kiowa Cos. GEN.: Petroleum reservoirs; exploratory drilling, 1938–1944; strength of the earth. ILL.: Rosiclare-Fredonia contact, Hardin and Pope Cos. ROCKY MTNS.: Developments, 1944.

NO. 12—132 pp. GEN.: Classification of oil and gas accumulations; use of aerial photographs; Permian Word formation; surface and seismic exploration party. TEX.: Coastal Plain Quaternary and Oakville, Cuero, and Goliad formations; Balcones, Luling, and Mexia fault zones; Pickton field, Hopkins Co.; Merigale field, Wood Co.

1946 VOL. XXX.—2120 pp. Each number ....($1.00) 1.50

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NO. 1—156 pp. CALIF.: Los Banos district, San Joaquin Valley. E. INDIES: Oil basins; reef corals. GEN.: Hydrocarbons from fatty acids; submarine slumping; Paleozoic conodonts; classification of oil possibilities; naming multiple sands. TEX.: Waller and Harris Cos.; Devonian "pay," TXL pool, Ector Co.

NO. 2—148 pp. ALA.: Pre-Selma Up. Cretaceous. ALBERTA: Jurassic-Cretaceous. GEN.: Origin of continental shelves. MONT.: Jurassic-Cretaceous boundary. ORE.: Up. Nehalem River basin. PERU: SE. reconnaissance. TEX.: Katy field, Waller Co.; Low. Pennsylvanian terminology.

NO. 3—172 pp. ECUADOR: Up. Cretaceous and Paleocene micropaleontology. EUROPE: Carpathian oil fields. GEN.: Porosity through dolomitization; members; financial. NEBR.: Boice shale, Mississippian. WEST VA.: Drill cuttings.

NO. 4—168 pp. ARGENTINA: San Pedro oil field, Salta. ARK.: Penters chert, Batesville. CALIF.: Miocene conglomerates, Puente and San Jose Hills. COLO.: Gramp's field, Archuleta Co. GEN.: Redox potential of marine sediments; asphaltic sands. MEX.: Caborca, Sonora. S. AM.: Tectonic framework. SINAI: Triassic conodonts.

NO. 5—168 pp. ALA.: Vick formation, pre-Tuscaloosa. GEN.: Organic material into petroleum; "Jacob staff"; aerial photography; annual reports and minutes; college geology students. KAN.: buried pre-Cambrian hills, Barton Co.

NO. 6—264 pp. RECENT DEVELOPMENTS. PERU: Southeastern reconnaissance. TURKEY: Harbolite, carbonaceous hydrocarbon.

NO. 7—144 pp. GEN.: Presidential addresses; science legislation; geologists in military service; production engineering; grain roundness; mss. preparation. TEX.: Gas reserves; Quaternary. VA.-TENN.: Ordovician.

NO. 8—212 pp. GEN.: Geological directory. KAN.: Siluro-Devonian. MON.: Ellis, Amsden, Big Snowy group, Judith basin. UTAH: Paleozoic-Mesozoic, Uinta Mtns.

NO. 9—188 pp. ALASKA: Possibilities. FRANCE: Aquitaine basin. GEN.: Quimbys Mill member, Platteville formation, Ordovician; oölite and oölith. GERMANY: Oil fields. S. AMER.: NW. framework. UNITED KINGDOM: Occurrence of oil.

NO. 10—176 pp. COLO.: Paleozoic, Las Animas arch, Baca, Las Animas, and Otero Cos. GEN.: Preparation of lantern slides. KAN.: Kinderhook dolomite, Sedgwick Co. N.MEX.-TEX.: Algae reefs, Ogallala formation, Llano Estacado Plateau. TEX.: Alunite at Woodbine-Eagle Ford contact. VENEZ.: Maracaibo basin.

NO.11—184 pp. ARIZ.: Faulting, Grand Canyon. GEN.: Fault structures; spectrochemical logging of limestones; well data and faulting; grain size in carbonate rocks; quotation mark in science; Jacob Staff measurements; organic material into petroleum; research schedule. N.MEX.-W.TEX.: Permian. N.CAR.: Atlantic Coastal Plain floor and continental slope. OKLA.: West Edmond field. TEX.: Hawkins field, Wood Co.

NO. 12—140 pp. GEN.: Oceans and continents; geological-geophysical exploration trends; exploratory drilling statistics; tectonics. OKLA.: Elmore embayment, Garvin Co. S. AMER.: Tectonic framework.


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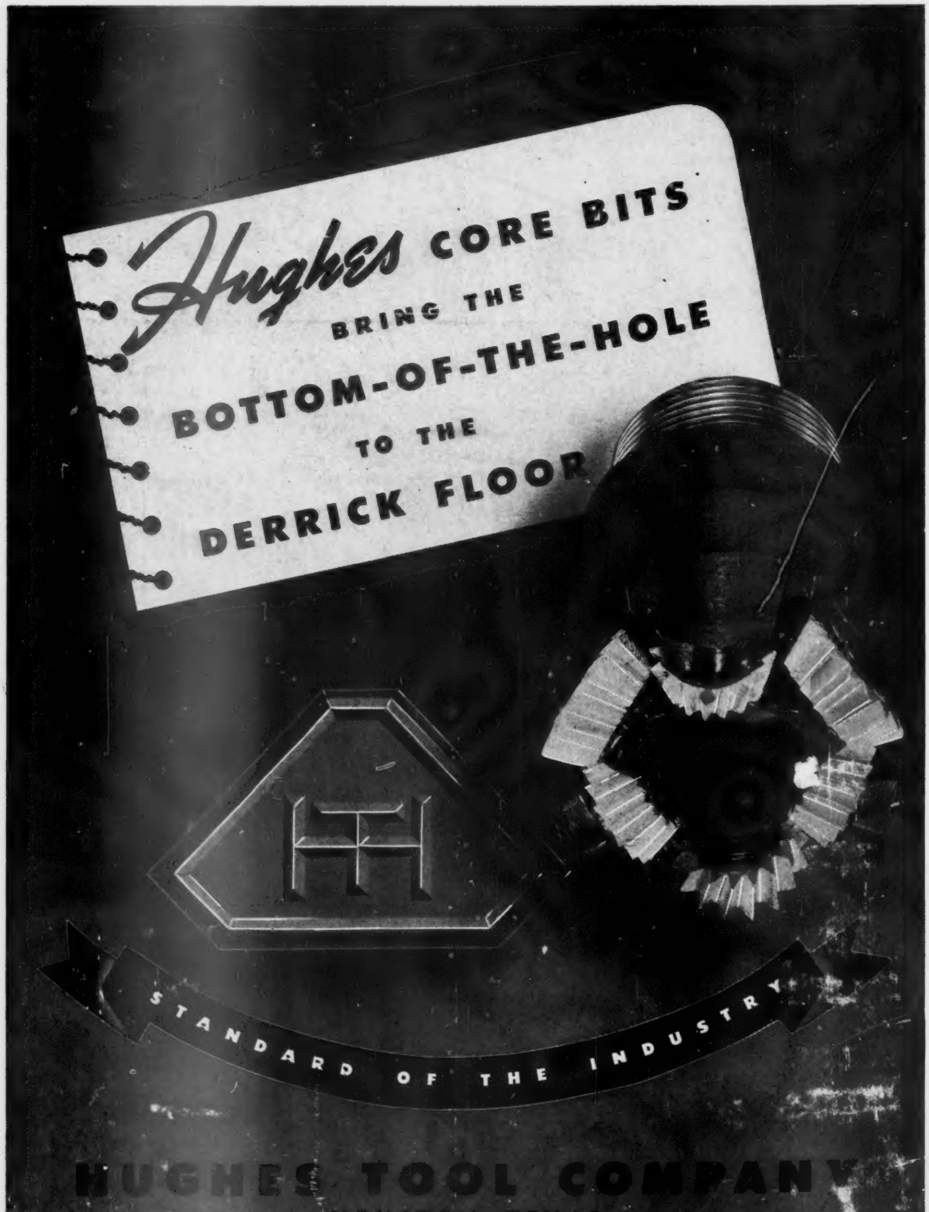
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